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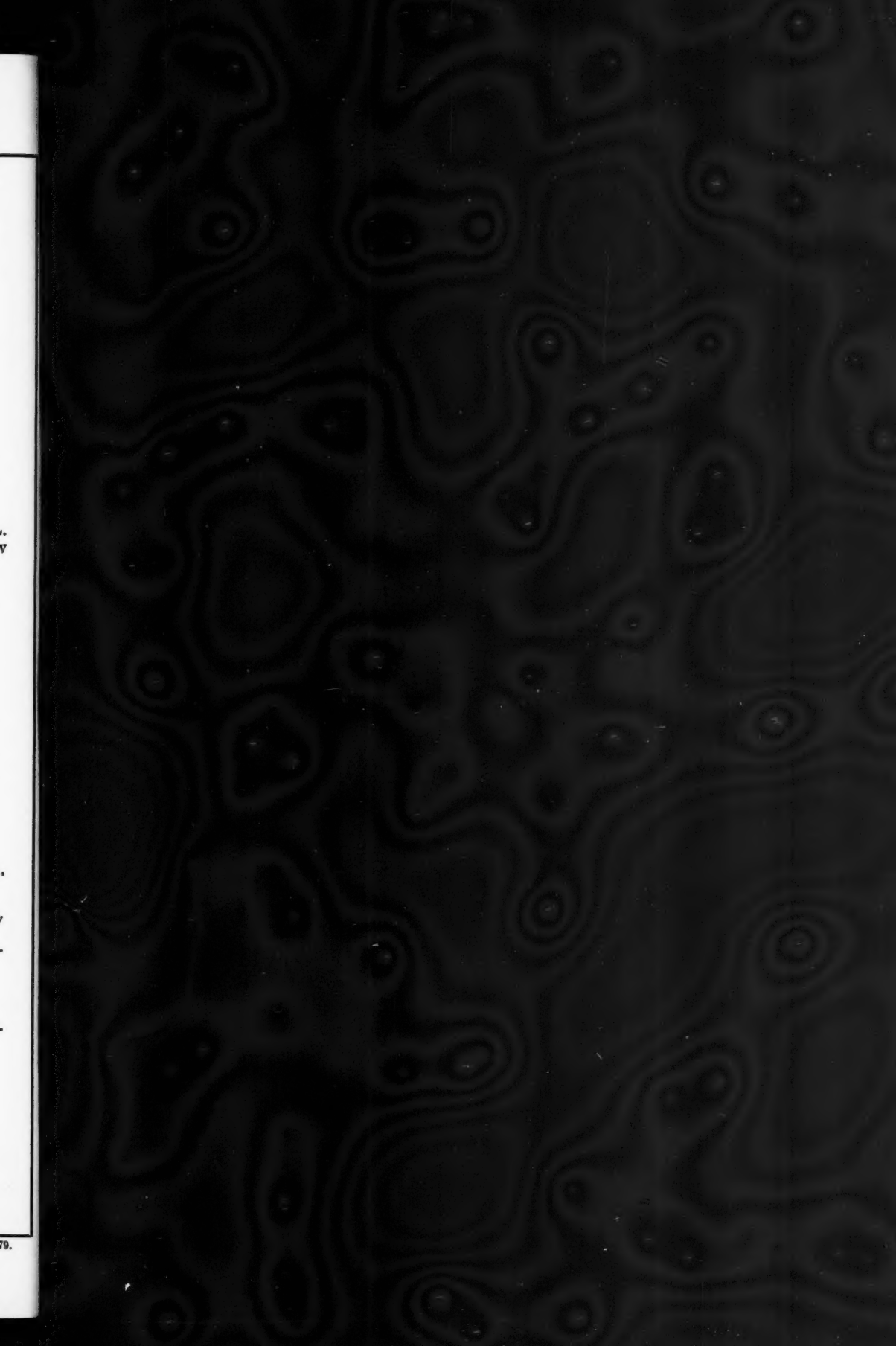

THE FEEDING POWER OF PLANTS FOR THE POTASSIUM IN FELDSPAR, EXCHANGEABLE FORM, AND DILUTE SOLUTION[1]

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Received for publication June 30, 1934

It is probably true, with a few exceptions, that 95 per cent or more of the potassium in soils exists in the form of feldspars and micas and is difficulty available. The readily available portion, consisting usually of not more than a few hundred pounds per acre in the plowed layer, exists in many soils almost entirely as exchangeable potassium.

Feldspars as a source of potassium for plants have been a subject of many investigations; for a review of the literature, the reader is referred to the articles by De Turk (3) and Haley (4). Because of variations in the amounts applied, differences in fineness of grinding, species of plants grown, and other experimental factors, the results reported by various investigators do not agree in all cases as regards the availability of feldspathic potassium.

The majority of investigators agree that exchangeable potassium is readily available. The literature regarding this matter is thoroughly reviewed in the recent papers by Hoagland and Martin (5) and by Magistad (10). The questions regarding the availability of potassium in exchange materials of varying degrees of saturation, however, have not been fully clarified.

The present investigation was undertaken to gain further information concerning the differences in the feeding power of various plants for the potassium in feldspars, in dilute solution, and in exchange materials of varying degrees of saturation.

PLANT FEEDING ON FELSPATHIC POTASSIUM

Methods

A study was made of the feeding power of 12 different crop plants for the potassium in feldspar. Two-gallon glazed earthenware jars, provided with a drainage hole, and filled with 10 kgm. of quartz sand, were used as culture vessels. The sand contained a trace of soluble potassium which was not washed out.

[1] Part of a thesis submitted to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the director of the Wisconsin Agricultural Experiment Station.

[2] The writer wishes to express his appreciation for the helpful suggestions and criticisms tendered by Professor E. Truog, under whose general direction the work was done.

The availability of an application equivalent to 2 tons to the acre of 180-mesh microcline feldspar, thoroughly mixed with the sand, was compared to that of a 100-pound per acre application of potassium as KCl. The KCl was dissolved and added with the nutrient solution. Salts free of potassium were used for supplying the other nutrients. Phosphorus in an amount equal to 0.007 per cent of the weight of the sand was supplied by mixing chemically equivalent quantities of $Ca_3(PO_4)_2$ and $FePO_4$ with the sand. Two solutions, made up separately so as to prevent precipitation of calcium as the sulfate, were prepared to supply the other nutrients, namely:

(A) 118 gm. of $Ca(NO_3)_2 \cdot 4H_2O$
Sufficient H_2O to give 1,000 cc. after solution
(B) 61.6 gm. $MgSO_4 \cdot 7H_2O$
0.15 gm. $MnCl_2 \cdot 4H_2O$
0.05 gm. NaI
Sufficient H_2O to give 1,000 cc. after solution

To each jar were applied 20 cc. each of nutrient solutions A and B, after these portions had been added to, and mixed with, about 500 cc. of water. More was added when needed.

Seven to ten days after the seeds were sown, the plants were thinned to the following number per jar: Corn, 3; alfalfa, alsike clover, red clover, and sweet clover, 20; and the others, 10. Care was taken to leave uniformly vigorous and well-distributed plants in each jar. After 45 to 60 days' growth, all crops except alfalfa, alsike clover, red clover, and sweet clover were harvested. The latter were grown 120 to 140 days. The plant tissue was dried at 75° to 80°C. and weighed. Buckwheat, alfalfa, and sweet clover were grown during both the 1933 and 1934 seasons; the other crops were grown only during 1933. The results are given in table 1, and figure 1 of plate 1 is illustrative of the results obtained with sweet clover.

Duplicate samples were composited, ground, and analyzed for potassium in the following manner: A 2-gm. sample of tissue was placed in a porcelain crucible, moistened with 5 cc. of an alcoholic 40 per cent $Mg(NO_3)_2 \cdot 6H_2O$ solution, the alcohol burned off, and the charred tissue ashed over a low flame. The bulk of the ash was taken up with water, transferred to a 250-cc. volumetric flask, the crucible rinsed with 2 cc. of concentrated acetic acid, and the solution made up to volume. Potassium was finally determined by the cobaltinitrite procedure as outlined by Volk and Truog (16). The results are given in table 2.

Results

In calculating the comparative yields in table 1, the yields obtained with soluble potassium are taken as a standard and expressed by 100, and the other yields are expressed as percentages of the standard. The results show that plants differ as regards their feeding ability for feldspathic potassium. It was found that corn, rape, buckwheat, peas, sorghum, sudan grass, soybeans,

TABLE 1

Yields, in grams of oven-dry material, of 12 different crops grown in quartz sand cultures supplied with readily soluble and feldspathic potassium

TREATMENT	YIELDS OF DRY TISSUE IN GRAMS			COMPARATIVE YIELDS
	A	B	Average	
1933 results				
Corn				
Soluble potassium	21.5	...	21.5	100.0
Feldspathic potassium	5.7	7.2	6.5	30.2
No potassium	2.8	4.2	3.5	16.3
Rape				
Soluble potassium	8.2	8.1	8.2	100.0
Feldspathic potassium	2.7	3.2	3.0	36.6
No potassium	2.1	1.7	1.9	23.2
Buckwheat				
Soluble potassium	5.9	6.8	6.4	100.0
Feldspathic potassium	2.6	2.5	2.6	40.6
No potassium	1.3	2.8	2.1	32.8
Alfalfa				
Soluble potassium	3.0	3.9	3.5	100.0
Feldspathic potassium	4.1	4.2	4.2	120.0
No potassium	2.5	2.2	2.4	68.6
Alsike clover				
Soluble potassium	5.1	4.0	4.6	100.0
Feldspathic potassium	4.3	4.5	4.4	95.7
No potassium	2.5	2.2	2.4	52.2
Peas				
Soluble potassium	6.7	6.6	6.7	100.0
Feldspathic potassium	4.9	3.6	4.3	64.2
No potassium	4.4	4.2	4.3	64.2
Sorghum				
Soluble potassium	30.0	31.0	30.5	100.0
Feldspathic potassium	7.0	5.8	6.4	21.0
No potassium	7.3	7.0	7.2	23.6
Sudan grass				
Soluble potassium	13.8	11.5	12.7	100.0
Feldspathic potassium	4.3	3.3	3.8	29.9
No potassium	3.0	3.7	3.4	26.8

TABLE 1—*Concluded*

TREATMENT	YIELDS OF DRY TISSUE IN GRAMS			COMPARATIVE YIELDS
	A	B	Average	
1933 results—Concluded				
Soybeans				
Soluble potassium	8.2	8.7	8.5	100.0
Feldspathic potassium	5.3	5.0	5.2	61.2
No potassium	5.8	4.9	5.4	63.5
Oats				
Soluble potassium	8.7	7.2	8.0	100.0
Feldspathic potassium	3.7	3.5	3.6	45.0
No potassium	2.8	3.0	2.9	36.3
Red clover				
Soluble potassium	4.8	5.1	5.0	100.0
Feldspathic potassium	5.5	4.2	4.9	98.0
No potassium	1.7	2.7	2.2	44.0
Sweet clover				
Soluble potassium	5.2	4.7	5.0	100.0
Feldspathic potassium	6.3	6.2	6.3	126.0
No potassium	3.3	2.5	2.9	58.0
1934 results				
Buckwheat				
Soluble potassium	13.3	11.0	12.2	100.0
Feldspathic potassium	2.4	1.4	1.9	15.6
No potassium	1.5	0.9	1.2	9.8
Alfalfa				
Soluble potassium	6.3	6.0	6.2	100.0
Feldspathic potassium	3.2	3.7	3.5	56.5
No potassium	0.5	0.4	0.5	8.1
Sweet clover				
Soluble potassium	6.3	5.8	6.1	100.0
Feldspathic potassium	3.3	3.3	3.3	54.1
No potassium	0.6	0.7	0.7	11.3

and oats were poor feeders; whereas alfalfa, alsike clover, red clover, and sweet clover were relatively good feeders on feldspathic potassium.

The poor feeders grown on feldspathic potassium showed symptoms of potassium deficiency soon after the first leaves appeared. In the case of the good

feeders, however, there were no signs of potassium deficiency until the later stages of growth (112 days in 1933, and 87 days in 1934).

The 1933 crops of sweet clover and alfalfa grown on soluble potassium were not so good as desired. The reason for this lack of vigor is unknown. This condition made the relative feeding power of sweet clover and alfalfa for feldspathic potassium appear abnormally high. In view of this fact, alfalfa and sweet clover, along with buckwheat, were again tested in 1934, when sweet clover and alfalfa made a normal growth on soluble potassium, and their

TABLE 2

Potassium content of 12 different crops grown in quartz sand cultures supplied with soluble and feldspathic potassium

CROP	POTASSIUM CONTENTS OF CROPS GROWN WITH ADDITIONS INDICATED					
	Soluble potassium		Feldspathic potassium		No potassium	
	Per cent	Mgm. per jar	Per cent	Mgm. per jar	Per cent	Mgm. per jar
1933 results						
Peas	1.66	111.22	0.28	12.04	0.23	9.89
Sorghum	1.14	347.70	0.27	17.28	0.23	14.56
Sudan grass	1.94	246.38	0.35	13.30	0.35	11.90
Soybeans	3.04	258.40	0.72	37.44	0.71	38.34
Oats	2.94	235.20	0.43	15.48	0.42	12.18
Corn	1.73	371.95	0.43	27.95	0.41	14.35
Rape	3.68	301.76	0.59	17.70	0.58	11.02
Buckwheat	1.94	124.16	0.64	16.64	0.63	13.23
Alfalfa	1.91	76.85	0.45	18.90	0.24	5.76
Alsike clover	2.04	93.84	0.42	18.48	0.24	5.76
Red clover	2.44	122.00	0.40	19.60	0.20	4.40
Sweet clover	2.12	106.00	0.44	27.72	0.23	6.67
1934 results						
Alfalfa	1.61	99.82	0.41	14.35	0.50	4.25
Sweet clover	1.48	90.28	0.59	19.47	0.85	5.95
Buckwheat	2.24	273.28	0.47	8.93	0.34	4.08

ability to feed on feldspathic potassium was confirmed. Buckwheat again exhibited poor feeding power for feldspathic potassium. The light conditions at Madison during the spring of 1934 were highly favorable to plant growth: more growth was obtained with sweet clover and alfalfa in 90 days in this season than in 120 days of the previous season. The normal growth on soluble potassium, together with the more rapid growth during this season, tended to reduce the apparent feeding power of alfalfa and sweet clover for feldspathic potassium. Perhaps the abnormal growth of the sweet clover and alfalfa during the spring of 1933 was due to the long periods of cloudiness that prevailed.

The potassium content of the alfalfa, alsike clover, red clover, and sweet clover crops grown on feldspathic potassium was significantly increased over that of the checks, as is shown in table 2. This is further evidence that these crops feed very markedly on the potassium in feldspar. The potassium content of the poor feeders, when grown on feldspathic potassium, did not show this significant increase.

Numerous theories regarding the feeding power of plants have been advanced. These are critically reviewed in a recent paper by Thomas (14). However, no theory has yet been advanced which adequately explains the differences observed in the feeding power of plants for feldspathic potassium.

Truog (15) suggested that good feeders obtain sufficient potassium from more dilute solutions than do the poor feeders. It appears from the work of previous investigators (2, 12) that plants do vary in their feeding power for potassium in dilute solution. In order to test this further, experiments were next conducted to determine whether the feeding power for feldspathic potassium was related to the capacity of a plant to obtain ample potassium from dilute solutions.

MINIMUM POTASSIUM CONCENTRATION NECESSARY FOR GOOD PLANT GROWTH

Methods

A study was made of the feeding power of buckwheat and red clover for potassium in dilute solution by means of flowing cultures. The culture vessels were 6-inch clay pots which had previously been heated and impregnated with paraffin. To each pot was added 2.5 kgm. of potassium-free sand. Sand cultures were used because they more closely approximate soil conditions as regards root development and aeration.

A nutrient solution, approximating in composition as regards the principal elements that found in the displaced solution of a very fertile soil, was prepared from potassium-free salts. It had the following composition:

Salts used, gm. per liter		*Elements furnished, p.p.m.*	
$Ca(NO_3)_2 \cdot 4H_2O$	0.5000	Calcium	160.0
$Ca(H_2PO_4)_2 \cdot 2H_2O$	0.0049	Magnesium	48.0
$CaCl_2 \cdot 2H_2O$	0.2756	Nitrogen	59.0
$MgSO_4 \cdot 7H_2O$	0.4866	Phosphorus	1.0
$MnCl_2 \cdot 4H_2O$	0.0004	Sulfur	63.0
NaI	0.00012	Chlorine	133.0
H_3BO_3	0.0006	Manganese	0.1
		Iodine	0.1
		Boron	0.1

About 2 liters of this solution percolated through each culture daily. Iron and additional phosphorus were supplied by adding and mixing 1.0 gm. $FePO_4$ with the sand of each culture. A potassium solution having a concentration of 1,000 p.p.m. of potassium was made by dissolving 1.9069 gm. of potassium chloride per liter. By adding from 0.5 to 7 cc. of this solution to each liter of

nutrient solution, potassium concentrations ranging from 0.5 to 7 p.p.m. of potassium were obtained.

The flow of the nutrient solution through the culture was controlled by the arrangement shown in figure 1. Reservoir R is fitted with an air-tight stopper S, and is connected to the constant level jar C by means of an air siphon AA'

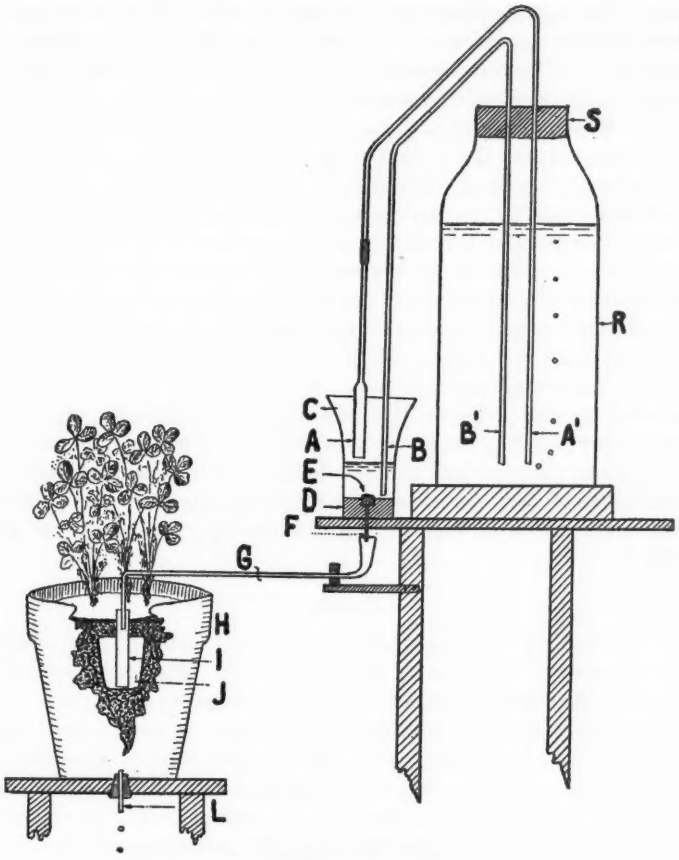

FIG. 1. APPARATUS FOR FLOWING CULTURE

and a water siphon BB'. Outlet B should be at least an inch below intake B', and intake A should be near the level of outlet A'. By extending the opening A' of the air siphon to the bottom of R, a more constant level is maintained in C than with an air siphon such as was used by Johnson (8). A constant level is maintained in C by the alternate operation of the water siphon, which creates a partial vacuum in the reservoir, and the air siphon, which releases

this vacuum when the water level in *C* drops below *A*. Jar *C* is provided with a No. 8 one-hole rubber stopper *D*. A 0.2-mm. capillary tube *F*, 2 inches long, is inserted partly through *D*. The capillary tube, such as used by Allison and Shive (1) and by others, was found to need frequent cleaning. This was effectively overcome by filling the upper portion of *D* with cotton E, which filtered out any foreign material, and needed to be changed only occasionally. The same capillary may be used to deliver different amounts of nutrient solution by raising or lowering the level of *A*, which changes the pressure on *F*. If several percolators or pots are to be treated with the same solution, *C* is provided with the necessary number of capillaries. The nutrient solution is delivered through *G* to the pot *H*, where it drops into a glass tube *I*, and is conducted to the bottom of the crucible *J*, which is buried 1 inch below the level of the sand. The sand in *J* becomes saturated, and by capillary action and gravity the nutrient solution becomes distributed throughout the pot. Channeling by the nutrient solution is thus prevented, and there is continuous displacement of the solution as it percolates through the culture. Glass wool is placed over the tube *L* to prevent the escape of sand as the nutrient solution leaches out of the percolator. This apparatus is simple to operate, requires but little attention, and can easily be constructed from materials common in the average laboratory.

As soon as the plants came up, the flow of the nutrient solution was started. Ten days after planting, the plants were thinned to 8 per culture, care being taken to leave vigorous and well-distributed plants. The buckwheat was harvested after 35 days' growth, and the red clover, after 50. The potassium content of the dry tissue was determined as before. The results are given in table 3.

Results

The data indicate that the minimum potassium concentration necessary for good growth of buckwheat is close to 3 p.p.m. The plants receiving 1 p.p.m. potassium exhibited distinct symptoms of potassium starvation. Those receiving 2 p.p.m. appeared healthy, but had spindly stems and small leaves; 3 to 7 p.p.m. gave luxuriant growth. On the other hand, a potassium concentration of only 1 p.p.m. appears to suffice for red clover. The plants receiving 0.5 p.p.m. potassium showed symptoms of potassium starvation. It is evident that where good growth begins, the potassium content increases considerably. The work of previous investigators (2, 12) indicates that sweet clover and alfalfa make good growth at 0.5 p.p.m. of potassium, while oats, soybeans, sudan grass, etc. require from 2 to 3 p.p.m.

It appears, therefore, that good feeders on feldspathic potassium can obtain sufficient potassium from more dilute solution than the poor feeders. The question then arises: what special mechanism do strong feeders have which enables them to obtain ample potassium from dilute solution? The answer is unknown at the present time. It is to be noted that the good feeders are

plants which have a high potassium requirement. The data in table 2 likewise indicate that these crops have actually absorbed more potassium when grown on feldspathic potassium than have the poor feeders. It may be that the good feeders have an absorbing membrane through which the potassium diffuses more readily from dilute solution than through that of the poor feeders. This, of course, is purely hypothetical.

Perhaps a factor in this question is the rate of growth. Alfalfa and the clovers are plants which take considerable time to establish themselves. It is to be noted, the poor feeders are plants which normally grow very rapidly at the seedling stage. It seems reasonable that a crop which normally grows slowly at this early stage would utilize more advantageously the dilute solutions of potassium released by the slowly hydrolyzing feldspars. On the other hand, crops such as buckwheat, because of their rapid growth, would appear to require higher levels of available potassium.

TABLE 3

Yields and potassium contents of plants grown in quartz sand cultures supplied continuously with a nutrient solution containing the concentrations of potassium indicated

POTASSIUM IN NUTRIENT SOLUTION	DRY BUCKWHEAT TISSUE		DRY RED CLOVER TISSUE	
	Gm. per pot	Per cent potassium	Gm. per pot	Per cent potassium
p.p.m.				
0.0	1.2	0.11	0.3	0.55
0.5	...	....	0.4	0.68
1.0	2.5	0.78	1.0	1.11
2.0	4.0	0.76	1.6	1.24
3.0	5.5	1.02	1.5	1.53
4.0	5.5	1.15	...	....
5.0	5.7	1.14	1.3	1.97
7.0	6.2	1.30	...	....

PLANT FEEDING ON EXCHANGEABLE POTASSIUM

Bentonite is a naturally occurring clay having pronounced base exchange properties which are believed to be due to substances similar to those occurring in mineral soils. It was thus selected as one of the exchange substances for this experiment. It is well known that organic matter possesses base exchange properties. In peats and mucks, the major portions of the exchangeable bases are held in the organic exchange materials, consequently more information should be had on the availability of the exchangeable potassium in these materials.

Preparation of materials

Potassium-saturated bentonite was prepared in the following manner: Raw bentonite was leached with a solution *N* with respect to KCl and 0.05 *N* with respect to HCl. The purpose of the acid was to remove $CaCO_3$. Leaching

was continued until the leachate gave no further test for calcium. The bentonite was then leached with a large volume of *N* KCl solution to saturate the bentonite with potassium. It was then washed with 85 per cent, by volume, alcohol until the leachate was chloride-free. The bentonite was partially dried, dispersed in water, and the suspension diluted to a large volume and permitted to stand overnight, so as to allow the coarser materials to settle. The supernatant suspension was siphoned off, evaporated to dryness, and the residue ground to pass a 100-mesh sieve. Analysis showed this material to be 93 per cent saturated with potassium. It had a pH of about 7.2.

Half-saturated potassium bentonite was prepared by treating hydrogen-saturated bentonite with K_2CO_3. Hydrogen-saturated bentonite was prepared in the following manner: Raw bentonite was dispersed in water, and the supernatant suspension was siphoned off and evaporated to dryness; the residue was ground to pass a 40-mesh sieve and leached with a solution *N* with respect to NH_4NO_3 and 0.05 *N* with respect to HNO_3. The NH_4NO_3 prevented excessive swelling of the bentonite. When the leachate was calcium-free, the excess NH_4NO_3 and HNO_3 were washed out with 85 per cent, by volume, alcohol, and the bentonite was dried and powdered. The remaining NH_4NO_3, HNO_3, and exchangeable NH_3 were driven off by ignition at 450°C. The hydrogen-saturated bentonite thus prepared was found to be NH_3-free. Sufficient potassium as a dilute solution of K_2CO_3 was added to just half-saturate the bentonite. After evaporation to dryness, the bentonite was ground to pass a 100-mesh sieve. It had a pH of about 5.7.

Saturated and half-saturated potassium-organic exchange materials were prepared in the following manner: Raw peat was leached with 0.05 *N* HNO_3 until free of calcium. The excess HNO_3 was washed out with distilled water, and the peat was dried. Two portions of this hydrogen-saturated material, the total exchange capacity of which had been determined by the usual method, were weighed out, and, to the first, sufficient potassium was added as a dilute K_2CO_3 solution just to saturate the exchange material, and to the second, just sufficient for one-half saturation. The mixtures were evaporated to dryness, and the organic exchange material was ground to pass a 100-mesh sieve.

Methods of plant culture

To prevent replacement of the exchangeable potassium by the bases of the other nutrients, Prianischnokov's (13) isolation method was used in which the exchange materials are placed in an inner jar so as to prevent contact with the nutrient solution, and part of the root system of each plant is looped into this jar so that it may feed on exchangeable potassium.

Potassium in the form of saturated and half-saturated potassium inorganic and organic exchange material and as KCl was added in all cases at the rate of 100 pounds per acre of elemental potassium. The treatments were tested in some cases in duplicate and in others in triplicate. The KCl was dissolved and added with the nutrient solution. Salts free of potassium were used for

supplying the other nutrients. Phosphorus was added to the sand of the outer jar in the manner described under the feldspar experiments. Three nutrient solutions were prepared to supply the other essential elements, namely:

(A) 50 gm. $Ca(NO_3)_2 \cdot 4H_2O$
Sufficient H_2O to give 1,000 cc. after solution
(B1) 26 gm. $MgSO_4 \cdot 7H_2O$
27 gm. $Mg(NO_3)_2 \cdot 6H_2O$
0.15 gm. $MnCl_2 \cdot 4H_2O$
0.05 gm. NaI
Sufficient H_2O to give 1,000 cc. after solution
(B2) 13 gm. $MgSO_4 \cdot 7H_2O$
14 gm. $Mg(NO_3)_2 \cdot 6H_2O$
0.15 gm. $MnCl_2 \cdot 4H_2O$
0.05 gm. NaI
Sufficient H_2O to give 1,000 cc. after solution.

Twenty cubic centimeters per pot of solutions A and B1 were added to corn, oats, and sudan grass. A nutrient solution having a higher Ca-Mg ratio (3 to 1) was supplied to the alfalfa as follows: Twenty cubic centimeters of solutions A and B2 were added to each jar, and additional calcium to increase the Ca-Mg ratio was supplied by mixing with the sand of the outer jar 0.26 gm. $CaSO_4$. The cultures were also inoculated. The potassium exchange material, mixed with some sand, was put into the inner jar, which was a glass vessel 4 inches in diameter and 5 inches in depth. The inner jar was then placed in the 2-gallon jar, the nutrient solutions were added and mixed with about 500 cc. of water, and the diluted solution was carefully added to the sand in the outside container.

Ten-day-old plants were transplanted to the jars, the root system of each plant being looped into the inner jar so it might feed on the exchangeable potassium. Sufficient moist sand, free of salts, was added to cover the roots of the plants. After 7 days, the corn was thinned to 3 plants per jar, and the other crops to 10. Care was taken to leave vigorous and well-distributed plants in each jar. After 45 to 60 days growth, the corn, sudan grass, and oats were harvested. The alfalfa was harvested after 120 days' growth. The tissue was dried at 75° to 80°C. and weighed; replicates were composited, ground, and in some cases analyzed for potassium as before. The results are given in tables 4 and 5, and figure 2 of plate 1 illustrates the results with sudan grass.

Results

In calculating the comparative yields in table 4, the yields obtained with soluble potassium are taken as a standard and expressed by 100, and the other yields are expressed as percentages of this. The data in table 4 show that the potassium held in organic and inorganic exchange materials is available to plants and that the availability of exchangeable potassium decreases with decreasing degree of potassium saturation of the exchange materials. Because

of the precautions taken to prevent replacement of potassium by the bases of other nutrients, it is evident that plants can feed directly on exchangeable

TABLE 4

Yields of oven-dry material of different crops grown in quartz sand cultures supplied with soluble and exchangeable potassium

TREATMENT	YIELDS IN GRAMS						AVERAGE YIELD TOPS AND ROOTS	COMPARATIVE YIELDS
	A		B		C			
	Tops	Roots	Tops	Roots	Tops	Roots		
Alfalfa								
Soluble K*	3.8	1.5	3.8	2.1	4.0	2.4	5.9	100.0
K-saturated inorganic exchange material	4.5	2.6	5.3	2.9	5.4	2.0	7.6	128.8
Half-K-saturated inorganic exchange material	4.2	1.9	5.0	2.3	5.2	2.8	7.1	120.4
No K	2.4	0.9	2.0	1.2	1.5	0.5	2.8	47.5
Oats								
Soluble K	12.0	4.9	10.4	3.2	11.3	3.0	14.9	100.0
K-saturated inorganic exchange material	11.2	2.5	10.0	4.8	10.2	3.5	14.1	94.6
Half-K-saturated inorganic exchange material	10.0	3.5	9.5	2.7	10.2	3.3	13.0	87.2
No K	6.3	1.5	6.0	2.2	5.8	2.5	8.1	54.4
Sudan grass								
Soluble K	11.5	13.5	8.7	13.0	....	....	23.4	100.0
K-saturated inorganic exchange material	6.3	12.7	7.5	9.5	....	....	18.0	76.9
Half-K-saturated inorganic exchange material	3.8	5.3	4.6	6.1	....	....	9.9	42.3
No K	1.3	2.3	1.5	3.2	....	....	4.2	17.9
Corn								
Soluble K	16.4	8.5	17.0	9.7	....	....	25.8	100.0
K-saturated inorganic exchange material	14.9	10.3	10.3	13.2	....	....	24.4	94.6
Half-K-saturated inorganic exchange material	14.3	8.0	15.2	6.3	....	....	21.9	84.9
No K	4.5	2.8	4.3	6.0	....	....	8.8	34.1
Corn								
Soluble K + H-saturated organic exchange material	14.0	11.3	14.3	14.2	....	....	26.9	100.0
K-saturated organic exchange material	12.8	13.7	13.5	13.3	....	....	26.7	99.3
Half-K-saturated organic exchange material	12.5	10.0	8.7	6.3	....	....	18.8	70.0
No K + H-saturated organic exchange material	2.8	1.7	3.3	3.5	....	....	5.7	21.2

* All replicates of this treatment with alfalfa damaged by mice.

potassium by exchanging the hydrogen ion of the carbonic acid secreted by their roots for the potassium in the exchange materials. Jenny and Cowan (7) report similar results for calcium.

The data in table 5 show that the plants absorbed considerable amounts of potassium from the exchange materials. There was a slight increase in the content of potassium in the crops grown on saturated potassium bentonite over those grown on half-saturated bentonite.

NATURE OF POTASSIUM IN SAP OF PLANTS

Our knowledge concerning the feeding power of plants for potassium would probably be somewhat clarified if more information concerning the nature of the potassium in the sap of plants, particularly as regards its solubility, were at hand. Kostytschew and Eliasberg (9) extracting dry tissue with water, Janssen and Bartholomew (6) microchemically precipitating the potassium in plant cells, and Morris (11) extracting fresh tissue with hot water, report that the potassium compounds in plants are in solution or in readily soluble forms. There is always the possibility that the treatments which they gave the plant tissue may have changed the potassium to a more soluble form. These treatments can be avoided by dialyzing the expressed sap of plants. From the slope of the dialysis rate curve, some idea may be obtained of whether or not the potassium in plant tissue is in solution. It is true that the tissue is killed by macerating and expressing the sap, but it is believed that this is the best available method for attacking the problem.

TABLE 5

Potassium content of some crops grown in quartz sand supplied with soluble and inorganic exchange potassium

CROP	PER CENT POTASSIUM IN OVEN-DRY TISSUE PRODUCED WITH POTASSIUM ADDITIONS INDICATED			
	Soluble potassium	Saturated potassium bentonite	Half-saturated potassium bentonite	No potassium
Oats	2.25	0.69	0.67	0.32
Alfalfa	2.20	1.61	1.59	0.67
Sudan grass	2.21	1.28	1.26	0.44

Dialysis of expressed sap

Fresh samples of rape, sweet clover, alfalfa, buckwheat, corn, and soybeans growing in the vicinity of Madison were collected and immediately placed in a jar and covered with cracked ice. On arrival at the laboratory, the tissue was ground and the sap immediately expressed with a pressure of 6,000 pounds per square inch for 5 minutes. Two 10-cc. aliquots of the expressed sap were taken, the first for total potassium analysis, and the second for dialysis. The latter was placed in a collodion bag which was hung in a beaker containing 500 cc. of water at 2° to 5°C. so that the potassium could dialyze out of the sap into the water. The low temperature minimized enzymatic activity during

dialysis. The water surrounding the collodion bag was stirred continuously for 3 hours, and the dialyzate was sampled regularly for potassium analysis. After the third hour, stirring was stopped, and the beaker with its contents was placed overnight in a refrigerator to come to final equilibrium. The results, which are given in tables 6 and 7 and figure 2, indicate that the potas-

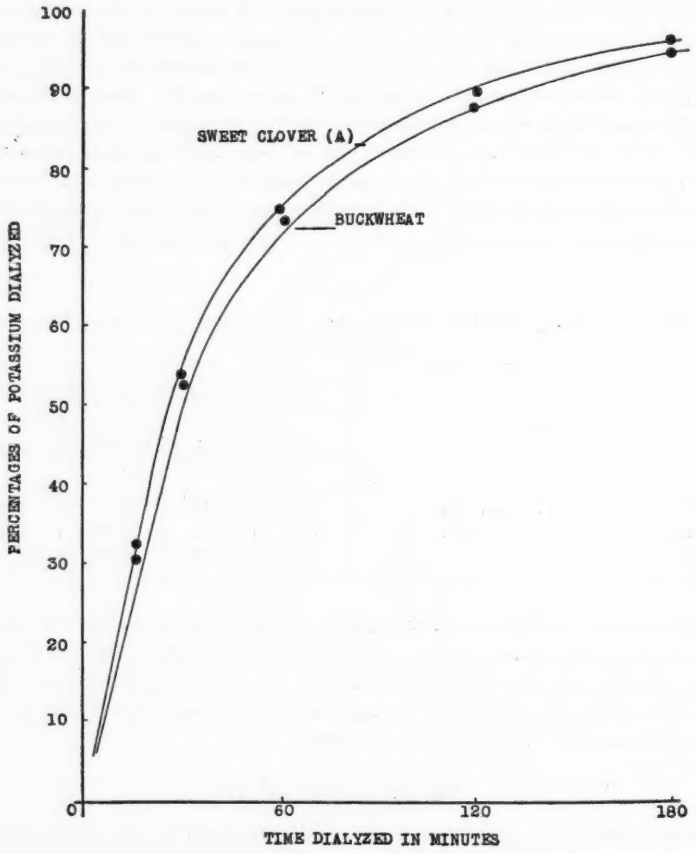

FIG. 2. RATE OF DIALYSIS OF POTASSIUM FROM THE EXPRESSED SAP OF SWEET CLOVER AND BUCKWHEAT THROUGH A COLLODION MEMBRANE

sium in the expressed sap of plants is practically all in dialyzable form. There is no significant difference in the rate of dialysis of potassium from the sap of various plants; this indicates a similarity of form.

The question arose as to how the plant sap dialysis curve would compare with that of a solution of a potassium salt. A KCl solution having the same

potassium concentration as the sap of sweet clover (A) was prepared. A 10-cc. aliquot of this solution was dialyzed under the same conditions as the plant saps. The results are plotted in figure 3. The curve shows a marked similarity in the slope and shape to that for the sap of sweet clover (A). This is evidence that the potassium in the expressed sap of sweet clover is practically all in solution. It was suspected that the slight lag in the rate of dialysis

TABLE 6

The total and dialyzable potassium in the expressed sap of different plants

PLANT	POTASSIUM IN 10 CC. EXPRESSED SAP	POTASSIUM REMOVED FROM 10 CC. EXPRESSED SAP BY DIALYSIS	DIALYZABLE POTASSIUM
	mgm.	*mgm.*	*per cent*
Rape	30.96	29.36	94.9
Sweet clover (A)	36.32	34.86	96.0
Sweet clover	36.37	34.63	95.2
Buckwheat	35.72	34.32	96.1
Alfalfa	61.92	59.90	96.7
Alfalfa	62.57	58.45	93.4
Corn	26.20	25.27	96.5
Soybeans	54.43	52.37	96.2

TABLE 7

The rate of dialysis of the potassium in the expressed sap of different plants through a collodion membrane

PLANT	PERCENTAGES OF POTASSIUM DIALYZED IN PERIODS INDICATED				
	15 minutes	30 minutes	60 minutes	120 minutes	180 minutes
Rape	30.0	50.8	69.9	85.8	92.5
Sweet clover (A)	32.7	54.0	74.4	89.5	96.4
Sweet clover	31.7	50.4	68.1	81.5	90.1
Buckwheat	30.4	52.5	75.1	87.2	94.6
Alfalfa	43.5	56.3	74.8	85.0	95.5
Alfalfa	33.4	44.6	67.0	82.0	87.2
Corn	43.4	59.9	84.2	98.3	99.3
Soybeans	33.0	54.9	67.5	87.4	92.2

of potassium from the sweet clover sap was due to suspended matter—chloroplasts, protein colloids, etc. In order to test this point, an amount of potassium equal to that in the sweet clover sap was added to a thick suspension of purified $Fe(OH)_3$, and dialysis was carried out as previously described. The curve plotted in figure 3 shows that suspended matter very markedly slows down the rate of dialysis of soluble salts and that the lag in the rate of dialysis of sweet clover sap was probably due to the suspended matter present.

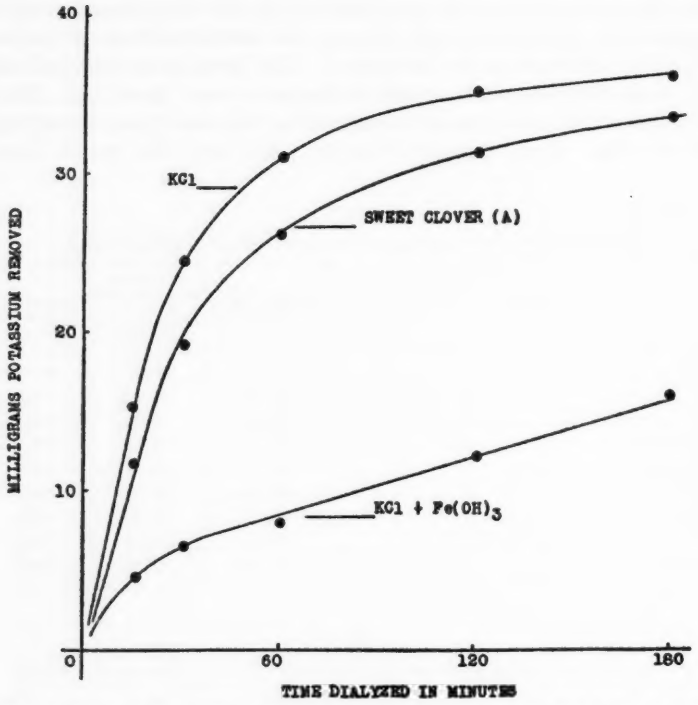

FIG. 3. RATE OF DIALYSIS OF POTASSIUM FROM SWEET CLOVER SAP COMPARED TO KCl SOLUTIONS CONTAINING EQUAL CONCENTRATIONS OF POTASSIUM, ONE WITH AND ONE WITHOUT $Fe(OH)_3$

TABLE 8

The total and dialyzable potassium in macerated bluegrass and sweet clover tissue

PLANT	TOTAL POTASSIUM IN TISSUE	POTASSIUM REMOVED FROM TISSUE BY DIALYSIS	DIALYZABLE POTASSIUM
	mgm.	*mgm.*	*per cent*
Bluegrass	74.59	73.50	98.5
Bluegrass	51.81	50.91	98.3
Sweet clover	38.63	38.15	98.8
Sweet clover	41.38	40.62	98.2

Dialysis of macerated tissue

To determine whether all the potassium in a plant is in solution or in a readily soluble form, macerated tissues of sweet clover and bluegrass, in place of the expressed sap previously used, were put into collodion bags which were hung in beakers of water and dialyzed at 2° to 5°C. The water in the beakers was

changed frequently. When the dialyzate gave no further test for potassium, the collodion bags and the macerated tissues were dried and ashed, and the potassium contents were determined. The results are given in table 8, and show that the potassium in macerated sweet clover and bluegrass tissues is practically all in a dialyzable form and hence in solution or readily soluble form.

Relation of results to plant feeding

Since the potassium in different plants seems to be very similar as regards solubility and form, it appears that the differences in feeding power of different plants are not related to any internal condition of the potassium and that these differences in feeding power will have to be explained on some other basis.

SUMMARY

The purpose of this investigation was to gain further information about the feeding power of plants for feldspathic and exchangeable potassium, and why there are differences in the feeding power of plants for potassium. The plants were grown in a greenhouse in quartz sand cultures, to which were applied: (*a*) feldspathic potassium, (*b*) exchangeable potassium, and (*c*) dilute solutions of water-soluble potassium. A study of the nature of the potassium in the expressed sap of plants was also made. The results of the investigation are as follows:

Corn, rape, buckwheat, peas, sorghum, sudan grass, soybeans, and oats were poor feeders on feldspathic potassium, whereas alfalfa, alsike clover, red clover, and sweet clover were relatively good feeders.

The potassium content of the alfalfa, alsike clover, red clover, and sweet clover plants receiving feldspathic potassium was significantly increased over those not receiving potassium, whereas that of the poor feeders did not show this significant increase.

Flowing cultures showed that the minimum concentration of potassium necessary for good growth of buckwheat is close to 3 p.p.m., but that about 1 p.p.m. suffices for good growth of red clover.

The feeding power of plants for the potassium of feldspars appears to be dependent on their ability to utilize more advantageously the potassium in dilute solution, which, in turn, may depend partly on the rate of plant growth.

The potassium in inorganic and organic exchange form is very readily available. Its availability decreases with a decreasing degree of potassium saturation of the exchange materials. Plant roots, by secreting carbonic acid, can feed directly on exchangeable potassium.

There is no significant difference in the rate of dialysis of potassium from the expressed sap of rape, sweet clover, buckwheat, alfalfa, corn, and soybeans; this indicates a similarity of form. The potassium in the macerated tissue of bluegrass and sweet clover is practically all in dialyzable form, and hence is in solution or in a state which readily hydrolyzes to a soluble form on dialysis. Consequently, the differences in feeding power are probably not related to any internal condition of the potassium.

The construction and operation of an apparatus for flowing cultures, which has several desirable features, is described.

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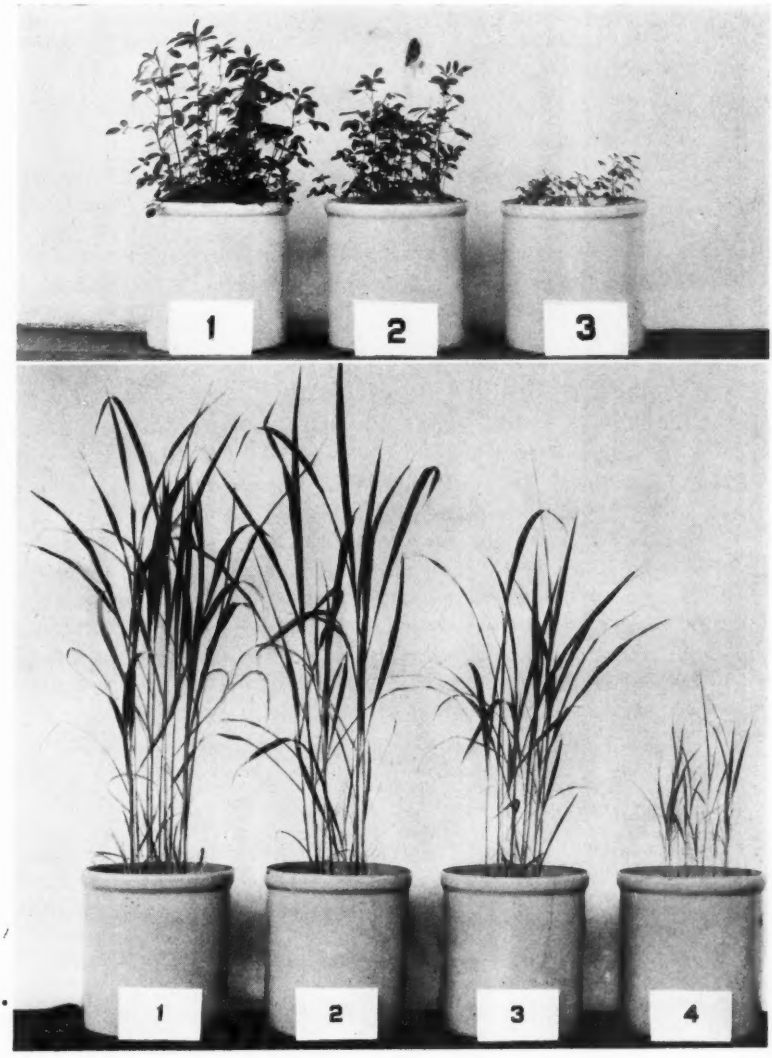
PLATE 1

GROWTH OF SWEET CLOVER AND SUDAN GRASS WITH VARIOUS POTASSIUM TREATMENTS

FIG. 1. Growth of sweet clover with the potassium treatments indicated. Jar 1, 100 pounds per acre soluble potassium; jar 2, 2 tons per acre feldspar; jar 3, no potassium.

FIG. 2. Growth of sudan grass with potassium treatments indicated. Jar 1, 100 pounds soluble potassium per acre; jar 2, 100 pounds potassium per acre as saturated inorganic exchange material; jar 3, 100 pounds potassium per acre as half-saturated inorganic exchange material; jar 4, no potassium.



UNIV. OF MICH.

TOLERANCE OF CERTAIN WEEDS AND GRASSES TO TOXIC ALUMINUM[1]

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In 1905 a series of experiments with lawn grasses was begun at the Rhode Island Agricultural Experiment Station. In several reports published since that time evidence has been given to show that the prevalence of weeds is less where the acidity of the soil is high. Although theories have been given to explain such a phenomenon, no facts have been developed to substantiate them.

Several workers at the Rhode Island station (3) and elsewhere have produced experimental evidence to show that soil acidity with its resultant depressing action upon plant growth is linked with toxic aluminum set free in the soil solution. Further attempts to clarify the picture have resulted in assigning to various crop plants (2) tolerance ranges within which certain quantities of aluminum fed to plants in solution cultures have been found to be toxic.

When we connect the knowledge of the lower prevalence of weeds on acid lawn soils and the relative sensitivity of crop plants it seems reasonable to suppose that weeds in general may have certain tolerance ranges and that individual species may vary as to their resistance to toxic aluminum. Such an assumption has led to an experiment to test the relative susceptibility of weed species commonly found in competition in lawn grass stands, and also, by way of comparison, the amounts of aluminum necessary to inhibit growth of some of the common lawn grasses have also been determined.

PROCEDURE

Seeds of the following weeds and grasses were collected and germinated in sand-soil mixtures in flats in the greenhouse.

1. *Cerastium vulgatum*.....Mouse-ear chickweed
2. *Stellaria media*.....Common chickweed
3. *Taraxacum officinale*.....Common dandelion
4. *Leontodon autumnalis*.....Fall dandelion
5. *Digitaria humifusa*.....Smooth crabgrass
6. *Digitaria sanguinalis*.....Rough crabgrass
7. *Prunella vulgaris*.....Heal All
8. *Setaria glauca*.....Yellow Foxtail
9. *Poa pratensis*.....Kentucky bluegrass
10. *Agrostis tenuis*.....R. I. (Colonial) Bent
11. *Agrostis alba*.....Redtop

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When the root systems had become established the soil was washed off the roots and the plants were mounted in perforated paraffined corks, six plants to each cork, and placed in 250-cc. bottles of nutrient solution. The basic nutrient solution used was a modification of Rhode Island solution A (1) having the following ingredients in 1 liter of solution.

Ingredients	*cc.*	*Molar*
$Ca(NO_3)_2 \cdot 4H_2O$	15	0.100
$MgSO_4 \cdot 7H_2O$	8	0.100
$Fe_2(NO_3)_6 \cdot 18H_2O$	4	0.003
KCl	8	0.100
$CaH_4(PO_4)_2H_2O$	8	0.010
NH_4NO_3	10	0.100

At all times and in all experiments the controls were grown in the solution given as above. The aluminum treatment was provided by using the alternating solution method adopted by McLean and Gilbert (2). By this method the plants were grown in solution A from Monday to Thursday of each week. They were then changed to a culture solution containing no phosphorus but having added to it the desired strength of aluminum in the form of aluminum sulfate. The acidity of certain of the control solutions was adjusted to that of the aluminum culture (pH 3.6–5.0) for additional proof that active acidity *per se* is not the cause of depressed growth.

PRESENTATION OF DATA AND DISCUSSION

In table 1 are given relative yields which show in a comparative way the sensitivity of the various plants studied. For greater ease of comparison the plants have been arranged in three groups according to their aluminum sensitivity, as follows:

Sensitive (depression 20 + per cent with 2–8 p.p.m. aluminum)
Mouse-ear chickweed, common chickweed, common dandelion, yellow foxtail, Heal All, and Kentucky bluegrass.

Medium Sensitive (depression 20 + per cent with 16–32 p.p.m. aluminum)
Fall dandelion and smooth crabgrass.

Resistant (depression 20 + per cent with 32–80 p.p.m. aluminum)
Rough crabgrass, redtop, and colonial bent.

It will be noted that Colonial bent and redtop required much higher concentrations to produce a depressed growth than did bluegrass. This is, of course, in line with the long-observed facts with regard to the growth of these plants on acid soils.

Observations of a more or less indefinite nature which have been made at the Rhode Island station from time to time have pointed to differences in the persistence of various weeds when under the same competition as to stand. Crabgrass is well-known as a persistent weed, whereas chickweed can be largely controlled by using sulfate of ammonia and by rendering the soil acid. These observations are in agreement with the ranges of sensitivity as given in table

TABLE 1

Relative yields of plants as affected by quantities of aluminum in solution

PLANT	SERIES	CHECK	RELATIVE YIELDS OF PLANTS WITH TREATMENTS OF									
			2 p.p.m. Al	4 p.p.m. Al	8 p.p.m. Al	16 p.p.m. Al	24 p.p.m. Al	32 p.p.m. Al	40 p.p.m. Al	60 p.p.m. Al	80 p.p.m. Al	Sulfuric acid
Group I. Depression 20+ per cent with 2–8 p.p.m. Aluminum												
Mouse-ear chickweed	I	100	62.0	54.8	56.5*	.....	27.8	....	....	15.7	....	91.3
	II	100	.....	66.9*	49.7	29.9	19.7	....	....	....	....	98.7
	III	100	.....	.....	64.7*	.....	.....	....	....	....	....	101.9
Common dandelion	I	100	.....	.....	49.3*	.....	.....	....	....	....	....	84.0
	II	100	29.0*	20.4	17.2	.....	.....	....	....	....	....	87.3
	III	100	37.9	20.4	21.4*	.....	.....	....	....	....	....	102.9
	IV	100	.....	70.3*	.....	.....	.....	....	....	....	....	106.8
Kentucky bluegrass	I	100	74.4*	88.4	33.9	.....	.....	....	....	....	....	114.0
	II	100	.....	52.8*	41.5	49.0	.....	....	....	....	....	94.3
Common chickweed	I	100	78.1	.....	46.1	31.3*	34.4	....	....	26.6	....	111.7
	II	100	98.5	.....	64.4*	.....	52.3	....	....	28.8	....	126.5
	III	100	.....	.....	80.4*	.....	.....	....	....	....	....	96.4
Heal all	I	100	.....	.....	50.0*	.....	.....	....	....	....	....	84.6
	II	100	.....	62.4	50.0	39.3	24.5*	....	....	....	....	108.0
Group II. Depression 20+ per cent with 16–32 p.p.m. Aluminum												
Fall dandelion	I	100	.....	.....	100.8*	.....	.....	....	....	....	....	142.1
	II	100	.....	.....	69.6	60.3*	47.6	....	....	11.8	....	96.9
	III	100	105.4	.....	83.1*	.....	54.7	....	....	28.4	....	98.0
	IV	100	.....	.....	.....	60.0*	.....	....	....	....	....	109.0
	V	100	.....	.....	73.7*	76.8	68.4	76.8	....	....	....	83.7
Smooth crabgrass	I	100	.....	.....	105.5*	93.0	82.5	75.2	....	....	....	113.0
	II	100	.....	.....	.....	100.0*	97.5	....	....	....	....	101.1
	III	100	.....	.....	.....	85.0*	75.2	....	76.0	....	....	65.9
	IV	100	.....	.....	.....	.....	97.0	....	94.1	....	....	100.0
	V	100	86.8	79.2	68.1*	.....	70.1	....	74.3	79.2	....	77.0
	VI	100	87.8	113.4	131.7	112.2	80.5*	....	76.8	75.6	....	.....
Group III. Depression 20+ per cent with 32–80 p.p.m. Aluminum												
R. I. bent	I	100	.....	89.0*	74.3	86.8	97.1	....	....	....	....	130.1
	II	100	.....	92.7*	127.6	84.5	84.5	....	....	....	....	87.9
Redtop	I	100	.....	117.2*	91.4	94.8	97.4	....	....	....	....	135.3
Rough crabgrass	I	100	.....	.....	.....	.....	84.9*	....	90.9	....	....	71.5
	II	100	.....	.....	.....	.....	71.9*	....	73.4	....	....	74.0
	III	100	132.5	82.5	106.1	88.6	144.7	....	89.5	129.8	97.4	.....
	IV	100	.....	.....	.....	.....	97.0*	....	94.0	....	....	100.0

* The asterisk designates the culture in each series having a pH comparable to the corresponding sulfuric acid culture.

1, crabgrass being very resistant and chickweed very sensitive to toxic aluminum.

As in former experiments (2) where the toxic effects of aluminum have seemed to be localized in the roots and evidenced by abnormal root growth, so with these weed species the root development was quite abnormal. Roots in the higher aluminum concentrations were brown in color with fewer rootlets and had definitely discolored root tips. That plants grown at acidities arranged by the use of H_2SO_4, and similar to the aluminum treatments, were not depressed in growth is shown by plate 1. Here common chickweed (*Stellaria media*) is shown with four treatments: check culture solution; with 8 p.p.m. of aluminum; with 60 p.p.m. aluminum; and with a solution adjusted to a comparable acidity by use of H_2SO_4. The relative yields of various plants with acidities so adjusted are shown in table 1. It is thus quite apparent that, as has been found in former experiments (1) with solution cultures, weeds grown at high acidities are not affected by acidity *per se*.

Finally it is suggested that, since there are such wide differences in sensitivity between the various weed species, the control of weeds in a competitive grass stand where soil acidity is maintained may be due, in part, to toxic aluminum. During the early stages of germination the newly formed tissues are soft and delicate and may be readily susceptible to aluminum toxicity. In this stage of plant development chickweed seedlings, being sensitive to small amounts of aluminum, might easily be killed. On the other hand, seedlings of crabgrass might survive under concentrations of aluminum which would be fatal to the chickweed seedlings.

SUMMARY

Experimental evidence is given to show that the various weed species commonly found in competition with lawn grasses vary greatly in their sensitivity to aluminum in solution cultures. From these facts it is suggested that toxic aluminum in the soil solution may be one of the causes of the inhibition of weed growth on acid soils.

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PLATE 1

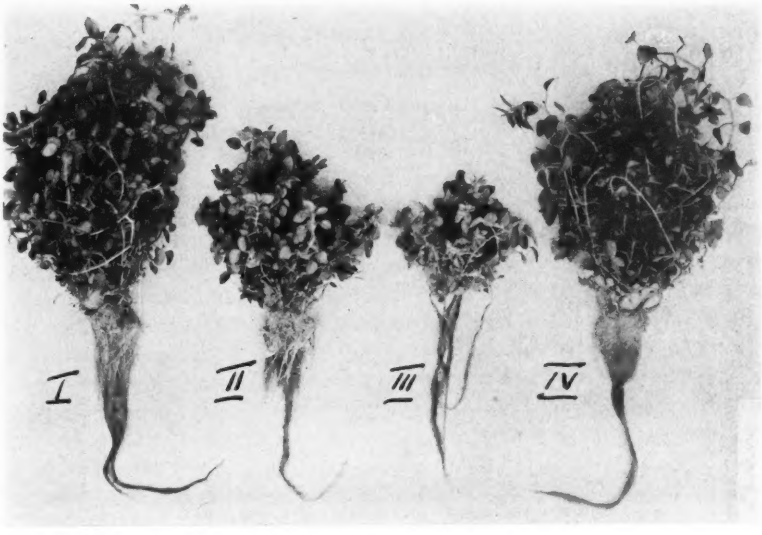
Effect of Aluminum on Common Chickweed (*Stellaria media*)

I. Check culture solution.

II. 8 p.p.m. aluminum.

III. 60 p.p.m. aluminum.

IV. Check culture solution adjusted to comparable acidity with aluminum treatments by use of sulfuric acid.


I
II
III
IV

RATES OF ABSORPTION OF AMMONIUM AND NITRATE NITROGEN FROM CULTURE SOLUTIONS BY TEN-DAY-OLD TOMATO SEEDLINGS AT TWO pH LEVELS[1]

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Considerable work has hitherto been published on the rates of absorption of ammonium and nitrate nitrogen by different species of plants from culture solutions, under various conditions of growth. It has been shown that, under similar experimental conditions, these absorption rates vary significantly for a given species at different stages during the growth cycle. It has also been shown that plants exhibit a very pronounced species difference with respect to the absorption and assimilation of nitrogen in the cation and anion forms.

For example, Stahl and Shive (6, 7), working with oats and buckwheat, found a very distinct contrast between these two species in their absorption rates of ammonium and nitrate nitrogen. With oats, the rate of ammonium-nitrogen absorption was greater than that of nitrate-nitrogen during the early stages of growth, but during the later stages the situation was reversed. During the greater part of the life cycle of this species, nitrate-nitrogen absorption predominated over ammonium-nitrogen absorption, both in actual quantity absorbed and in rate, or quantity, absorbed per unit of plant tissue, when both forms were present simultaneously in the growth medium at approximately equal concentrations.

With buckwheat, on the contrary, ammonium-nitrogen absorption predominated over nitrate-nitrogen absorption during the greater part of the active life cycle of the plant. The nitrate absorption rate exceeded the ammonium absorption rate only in the very late stages of growth when the absorption rates of both were relatively low. Thus, the buckwheat may be spoken of as an "ammonium absorber," in contrast to the oat plant, which may be considered as a "nitrate absorber."

More recent work by Clark and Shive (1) with the tomato plant has shown that during the middle and later stages of growth this species shows a close parallel to the oat plant in its tendency toward nitrate absorption, as predominant over ammonium; but Clark and Shive did not determine the rates of nitrogen absorption by this plant at a very early stage of development. It is the purpose here to present briefly the results of tests made with tomato

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of plant physiology.

seedlings at as early a developmental stage as was experimentally practicable, and thus to fill in this rather important gap left vacant in their work.

METHODS OF EXPERIMENTATION

The plants used for this test were young seedlings 10 days old from germination. The first foliage leaf of each seedling was just beginning to enlarge when these tests were made. The seeds were germinated and the seedlings grown by the same general methods, with slight modifications, as were used and described by Stahl and Shive (7) in similar work with buckwheat seedlings. After germination between moist blotting papers, the seeds were transferred to paraffined cloth nets supported on shallow glass dishes, each dish containing approximately 400 cc. of culture solution. On each net, 250 germinated seeds were placed.

TABLE 1

Composition of solutions used

Basic solution at a concentration of 1 atmosphere

SOLUTION DESIGNATION	PARTIAL VOLUME-MOLECULAR CONCENTRATIONS			
Modified Tottingham.....	KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	$(NH_4)_2SO_4$
$T_3R_2C_2$.....	0.00211	0.0029	0.0071	0.0028

Modifications

QUANTITY	ACID AND ALKALI PER LITER	RESULTING pH
cc.		
0.14	Normal H_2SO_4	4.0
2.25	Normal KOH	7.0

The solution used for growing and testing these seedlings was the $T_3R_2C_2$ solution of the four-salt Tottingham type, modified by Jones and Shive (3) to contain ammonium sulfate, and was identical with the culture solution employed by Clark and Shive (1). This particular solution contains approximately equal molar concentrations of ammonium and nitrate nitrogen, and was here further modified, as was also done by Clark and Shive (1), to contain only one-third as much monopotassium phosphate as the original solution, in order to lessen the tendency toward precipitation of the phosphate ion in combination with the other ions in the final solution when employed at pH 7.0.

For the first 2 days after the germinated seeds had been transferred to the nets, the solution was supplied continuously to the seedlings at one-tenth atmosphere osmotic concentration. For the following 3 days it was then supplied at one-quarter atmosphere, after which time the plants were grown and tested in the solution at approximately eight-tenths atmosphere. All the cultures were grown, up to the time of testing, in the culture solution at the

same pH level: pH 5.3. In view, however, of the recent work by Clark and Shive (1), who showed that a significant relationship exists between the pH of the culture solution and the rates of absorption of the two forms of nitrogen, the tests were made at two different pH levels: pH 4.0 and pH 7.0. The quantities of salts, acid, and alkali used in making up this solution at the final concentrations and at the pH levels used are given in table 1. Boron, manganese, and iron, in the forms of boric acid, manganese sulfate, and ferrous sulfate, respectively, and in quantities of 0.5 p.p.m. of each, were added to all solutions used.

The tests for absorption rates were carried out during the middle of the day, under conditions of bright sunlight and active transpiration. The absorption interval extended over a period of 6 hours, during which time the roots of the seedlings were immersed in 350 cc. of the culture solution that had been measured into the rinsed containers at the beginning of the test period. During the absorption interval of 6 hours, 250 cc. additional solution was dripped through each culture vessel by the continuous flow method used and described by Shive and Stahl (5).

At the end of the absorption interval, the container of each culture was carefully emptied and, together with the net and roots, rinsed clean of solution. The test solution and rinse water were combined and made up to a volume of 1 liter. The analyses of the test solutions for the two forms of nitrogen, both before and after contact with the roots of the seedlings during the test intervals, were carried out by the methods used and described by Clark and Shive (1), and the amounts of nitrogen absorbed by the seedlings were calculated by difference.

EXPERIMENTAL RESULTS

The absorption data for these young seedlings are presented in table 2. All values are calculated in terms of milligrams of nitrogen absorbed per 10 gm. of green weight of plant tissue in 6 hours.

The first point which stands out clearly is the fact that for these young tomato seedlings, under the experimental conditions here defined, the rates of absorption of nitrate nitrogen greatly exceed the rates of absorption of ammonium nitrogen at both high and low pH levels. Direct comparison shows the average nitrogen-anion absorption rate values to be 4.7 and 1.2 times the corresponding cation-nitrogen absorption rate values at pH 4.0 and pH 7.0 respectively. This is in direct contrast with the results obtained by Jones and Skinner (2) for soybeans and corn, by Naftel (4) for cotton, and by Stahl and Shive (6, 7) for oats and buckwheat.

In considering now the ammonium- and nitrate-nitrogen absorption rate values separately, it will be observed that the data indicate much higher cation-absorption rates from solutions at pH 7.0 than from solutions at pH 4.0, the rates at pH 7.0 being more than three times as high as the corresponding rates at pH 4.0. This again emphasizes the point brought out by Clark and

Shive (1) that the pH of the culture medium appears to be the dominating factor in determining the rate of absorption of cation nitrogen by the tomato plant. On the other hand, the rate of absorption of anion nitrogen from solution at pH 4.0 was somewhat higher than the corresponding rate of absorption from solution at pH 7.0, but pH of the culture solution did not have the same pronounced influence in determining the rates of anion-nitrogen absorption as it did in determining the rates of cation-nitrogen absorption. This also is in entire agreement with the results obtained by Clark and Shive (1) with tomato plants at later stages in the growth cycle.

The point to be emphasized in these studies with young tomato seedlings is that the average maximum ammonium-nitrogen absorption rate, at pH 7, although decidedly higher than the corresponding rate at pH 4, was still significantly lower than the minimum-nitrate absorption rate at pH 7. In this

TABLE 2

Milligrams of ammonium and nitrate nitrogen, per 10 gm. green tissue, absorbed in 6 hours by 10-day-old tomato plants from culture solutions at two pH levels

CULTURE NUMBER	pH	NUMBER OF PLANTS	GREEN WEIGHT	NITROGEN ABSORBED			
				NH_4-N		NO_3-N	
				Individual	Average	Individual	Average
			gm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*
1	4.0	238	13.7	0.67	0.85	4.50	3.95
2	4.0	213	13.7	1.22		3.62	
3	4.0	234	13.7	0.90		4.34	
4	4.0	215	15.2	0.61		3.34	
5	7.0	228	12.2	2.35	2.64	3.30	3.19
6	7.0	234	10.0	2.87		3.47	
7	7.0	230	10.8	2.45		3.72	
8	7.0	231	11.5	2.88		2.25	

respect the tomato shows a very distinct difference from the other species previously studied. It will be recalled from the work of Stahl and Shive (6, 7) and from that of Naftel (4), that in the case of oats, buckwheat, and cotton the ammonium-nitrogen absorption predominated over the nitrate-nitrogen absorption in the young stages of growth and then rapidly decreased, and that the nitrate-nitrogen absorption rates gradually increased and assumed the ascendancy during the later stages of the growth cycle.

In the tomato plant, on the other hand, under optimum conditions, nitrate-nitrogen absorption rates generally predominated over ammonium-absorption rates throughout the entire growth cycle. In this respect the facts indicate that the tomato plant may be regarded distinctly as a nitrate absorber when nitrogen is present in the growth medium in both the cation and anion forms simultaneously and in approximately equal molar proportions, but at no time

in the active growth cycle has it been found that the tomato plant actually ceases to absorb cation nitrogen in the presence of an available supply of this form.

Like other species previously studied, the tomato plant showed maximum absorption rates of cation nitrogen during the seedling phase of growth. These rates then rapidly declined with the age of the plant and seldom predominated over the anion-absorption rates. Unlike other species previously studied, the tomato plant also showed maximum absorption rates of anion nitrogen during the seedling phase of growth, and these rates exhibited marked superiority over maximum rates of absorption of cation nitrogen.

Because of the pronounced tendency of the tomato plant to remain very vegetative as long as favorable growth conditions prevail, it is to be expected that this plant should exhibit some absorption characteristics different from those of other species previously studied. However, this does not explain why some species are predominantly nitrate absorbers, while other species are predominantly ammonium absorbers, when the two forms of nitrogen are simultaneously present in the growth medium.

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APPARATUS FOR THE DETERMINATION OF CO_2 IN CULTURE SOLUTIONS[1]

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During an investigation of the relationship between the aeration of culture solutions and the rates of nitrogen absorption by the plants growing therein, it became necessary to make quantitative determinations of the soluble carbon dioxide content of the culture solutions at periodic intervals. In order to make these determinations without exposing the test samples to the atmosphere, which might interfere with the accuracy of the tests, the special apparatus herein described was designed and used.

The acidimetric method of analysis was used, a description of which may be found in any standard work on quantitative analysis (3). Briefly stated, this method involves the absorption of the carbon dioxide by standard alkali, through which it is bubbled, and the precipitation as the insoluble barium salt of the carbonate thus formed. The exact amount of alkali thus neutralized is calculated by titrating, with standard acid, the excess alkali remaining after absorption is complete. The amount of carbon dioxide present in the solution may then be calculated directly in terms of parts per million, or milligrams of CO_2 per liter of solution.

Mack (2) describes an ingenious apparatus embodying the aforementioned principle, which he used to measure the amount of CO_2 evolved from solution cultures. It was so devised as to enable one to titrate the absorbing alkali without exposing it to the atmosphere, precluding what might have been a serious error. The absorption tower in this device consisted of a large-bore glass tube partially filled with small glass beads, a unit which is frequently used in apparatus of this type.

In the present work of estimating rather minute quantities of CO_2, it was observed that in order thoroughly to remove the residual alkali from the absorption tower to the titration flask, a very appreciable quantity of wash water was necessary. As a consequence, the original alkali, which was necesarily quite dilute because of the small quantities of CO_2 to be assayed, was just so much further diluted, and this interfered with the obtaining of a sharp end point in the titration.

The apparatus herein described circumvents this difficulty. Since the

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of plant physiology.

investigation was concerned with the total dissolved CO_2 in a solution at a specified time, the method devised by Allison and Shive for collecting the sample and aliquoting it with a minimum exposure to the atmosphere was here used (1).

The apparatus as diagrammed in figure 1, is made up of two distinct sections. The section on the left, containing the long tube *A*, served for the absorption of the carbon dioxide by the alkali and the subsequent titration. That part of the apparatus on the right, including tube *B*, served for the liberation of the CO_2 from the sample solution. This was accomplished by making the solution strongly acid with approximately 2 *N* HCl.

In order to describe the apparatus with as little confusion as possible, the various steps in the analysis of a sample will be followed through in order.

The first step is to remove the absorption tube *A* and the reaction tube *B* from the apparatus after the previous determination. These are thoroughly cleaned and rinsed, as are all of the parts contained within the tubes. Tube *A* is replaced, after a few drops of phenolphthalein indicator have been introduced into it. Tube *B*, now containing 5 cc. of 2 *N* HCl which later provides the means of acidifying the test solution sample when it is admitted to tube *B*, is also replaced. The sample bottle containing the test sample is next attached as shown in the figure.

Suction is then applied at *Y*, with the pinchcock P_3 closed, the stopcock of burette *F* closed, and the two-way stopcock *K* above the sample bottle turned as shown in the figure. Air enters the system through the soda-lime tube *M*, and all parts of the system between *M* and *Y* are thus freed of carbon dioxide.

Suction is then stopped at *Y* and applied at *X* with the same water pump. With pinchcock P_1 open, stopcocks of all burettes, *C*, *E*, and *F* closed, and P_4 on tube *D* closed, air enters this part of the system through the soda-lime tube *L* until it, too, is filled with CO_2-free air. This is demonstrated by closing the pinchcock P_1 and allowing the air stream to pass through the telltale tube T_1, filled with saturated barium hydroxide solution. Any trace of carbon dioxide in the air stream can be at once detected by this means. After it is certain that all parts of the apparatus are free of carbon dioxide, it is then ready for the analysis of the test sample.

Continuing suction at *X*, the standard alkali is admitted to the 100-cc. thick-walled test tube *A*. The alkali is accurately measured from burette *E* and conducted into tube *A* by the small funnel *O* on the end of a long glass tube of from 1.5-to 2-mm. bore, as shown in the diagram. Through this long inlet tube are also drawn the air and, later, the air-CO_2 mixture, from the reaction tube *B*, as well as all other material which entered the absorption tube *A* at any time during the determination. This, as well as the manner of admitting the sample solution to the reaction tube *B*, makes it possible to carry through the entire process without opening any part of the apparatus to the atmosphere.

The long inlet tube just mentioned is provided with a small hooked bend at its tip, on which rests a special piece of spirally coiled glass tubing. This glass

coil is formed around a central hollow glass tube of 1.3 cm. diameter as a core, and is sealed at both ends to prevent entrance of any materials. The glass coil fits rather loosely against the walls of the absorption tube, but just tightly enough so that the bubbles of air, or air-CO_2 mixture, released at the bottom

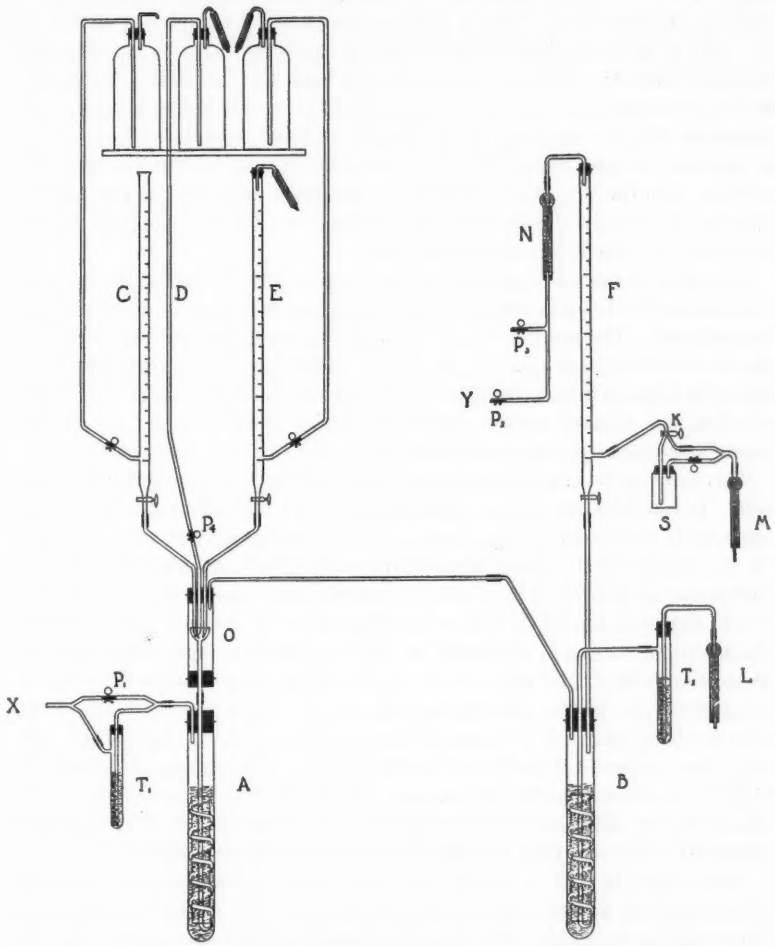

FIG. 1. APPARATUS FOR THE DETERMINATION OF CO_2 IN CULTURE SOLUTION

do not rise vertically through the alkali in the absorption tube *A*, but instead slowly follow a spiral path, guided by the surface of the glass coil between the walls of tube *A* and the core of the spiral. A sufficient quantity of alkali is used to cover completely the coil in the tube. By means of a screw clamp at

X the suction can be carefully regulated so that the bubbles are allowed to pass rather slowly through the alkali, thus insuring complete absorption of the CO_2 as it is released from the solution sample in tube *B* and carried over into tube *A*.

The next step in the procedure is to open the two-way stopcock above the sample bottle *S* in the opposite direction, and to draw some of the sample solution up into burette *F*. This is easily accomplished by applying suction at P_3. The level of the liquid in the burette is easily regulated by the two-way stopcock, allowing any excess solution to flow back into the bottle. Inasmuch as the test solution is now in contact with CO_2-free air in the burette, it is important that the next step in this procedure should be performed as quickly as possible, in order to prevent any appreciable diffusion of the gas from the solution into the air. Consequently, a measured quantity of the sample solution is quickly drawn from the burette into the reaction tube *B*, the suction at *X* being continued all the while.

Inasmuch as the acid is already in the reaction tube *B*, the sample solution becomes acidified as it is admitted, and thus liberation of carbon dioxide starts immediately. The reaction tube *B* contains a glass spiral and core similar to that in the absorption tube *A*. As the air stream entering through the soda-lime tube *L* passes in small bubbles spirally upward through the acidified sample solution, the released carbon dioxide is carried along with it, and thence passed over into the absorption tube *A*.

This aerating process is continued during a period of 10 minutes for each test. It had been previously ascertained that all the carbon dioxide can be removed in this period of time from a solution sample such as was here used. At the end of this 10-minute interval, the excess alkali not neutralized by the carbon dioxide is titrated by admitting standard acid directly from the burette *C* into the small funnel *O*, without opening any part of the system. During the titration, suction is continued in order to draw the acid down into the absorption tube *A*, and the bubbles continually passing through the solution serve effectively to mix the acid and the alkali. When the end point of the titration is approached, CO_2-free distilled water is admitted through the tube *D* to rinse the walls of the funnel and inlet tube. The reading of the burette *C* gives the exact quantity of standard acid required to neutralize the excess alkali, and by difference the exact quantity of carbon dioxide liberated from the sample aliquot is then computed in terms of parts per million.

Approximately 0.02 *N* NaOH was used as the absorbing agent in these determinations, and this was standardized against 0.07 *N* H_2SO_4, methyl red being used as indicator. For the titration, 0.1 *N* HCl was employed, with phenolphthalein as indicator. This acid was made up with barium chloride in solution at a 1 per cent concentration. This solution contained a sufficient quantity of barium chloride per cubic centimeter (calculated) to react in excess with all the carbon dioxide released from any of the samples analyzed.

Tables 1 and 2 illustrate, in a measure, the degree of accuracy which may be attained with this apparatus. Table 1 gives the values for CO_2 calculated and

recovered from samples of a CO_2-free culture solution to which had been added known quantities of Na_2CO_3.

Table 2 presents the quantitative data representing the CO_2 obtained by the analysis of duplicate samples of culture solutions which had previously been in contact with the roots of experimental plants for a definite period of time. The samples were taken while the roots of the plants were still immersed in the solutions maintained at different pH levels. The table is here introduced to

TABLE 1

Analysis of known samples of a culture solution

SAMPLE		CO_2	
		Calculated	Recovered
		mgm.	*mgm.*
10 mgm. Na_2CO_3 in each sample of the culture solution	1.....	4.09	4.00
	2.....	4.09	4.15
	3.....	4.09	4.03
	4.....	4.09	4.12

TABLE 2

Analysis of duplicate unknown samples of culture solutions after contact with the roots of growing plants during a definite time interval

SAMPLE	pH OF CULTURE SOLUTIONS	CO_2
		mgm.
1	4	0.61
Duplicate	4	0.63
2	7	1.32
Duplicate	7	1.39
3	4	0.72
Duplicate	4	0.72
4	7	2.38
Duplicate	7	2.42

indicate the approximate agreement which may be expected between tests of duplicate samples when the analyses are carried out with the apparatus here described.

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THE RELATION OF POTENTIAL ALKALINITY TO THE AVAILABILITY OF PHOSPHATE IN CALCAREOUS SOILS

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The use of phosphate fertilizers in the irrigated regions of the Southwest has increased notably during the last few years and is a practice which is yielding profitable returns. The soils are with few exceptions alkaline calcareous types, and the problems connected with phosphate fertilization are extremely varied and of great economic as well as scientific interest. There is no deficiency of potential phosphate reserve in any of these soils. The apparent deficiency is due to characteristic soil properties which govern the solubility and availability of the phosphate and the absorptive activities of the roots. In fact, even a supply of phosphate in the soil solution does not necessarily insure the crop against phosphate starvation.

PHOSPHATE COMPOUNDS AND THEIR SOLUBILITY

Phosphate is present in these alkaline calcareous soils, in most part, as carbonato-apatite (calcium carbonato-phosphate), a compound composed of three mols tri-calcium phosphate and one mol calcium carbonate, with small amounts of iron and aluminum phosphate (4). Extensive solubility studies on these soils have shown that those within the reaction range represented by the limits pH 8.0 and 8.5 contain the smallest amounts of soluble phosphate (3). The reason for this is illustrated by the curves given in figure 1, in which solutions of ferric phosphate, aluminum phosphate, dicalcium phosphate, and phosphate rock were adjusted to various concentrations of hydrogen or hydroxyl ions and the changes in solubility noted. The solubility curves for the calcium phosphates are of the descending order as pH is increased, whereas the solubility curves for iron and aluminum phosphates are of an ascending order with increase in pH where black alkali (NaOH) is present and of the descending order where lime alkalinity [$Ca(OH)_2$] is present. Under many soil conditions carbonato-apatite is a readily available form of phosphate. Reference is made to acid soils, neutral soils, and certain slightly alkaline soils which contain no solid phase calcium carbonate. Under the soil conditions which exist in the Southwest, namely, an alkaline reaction and an abundance of solid phase calcium carbonate, its solubility is at a minimum and usually fails to supply the requirements of the crop.

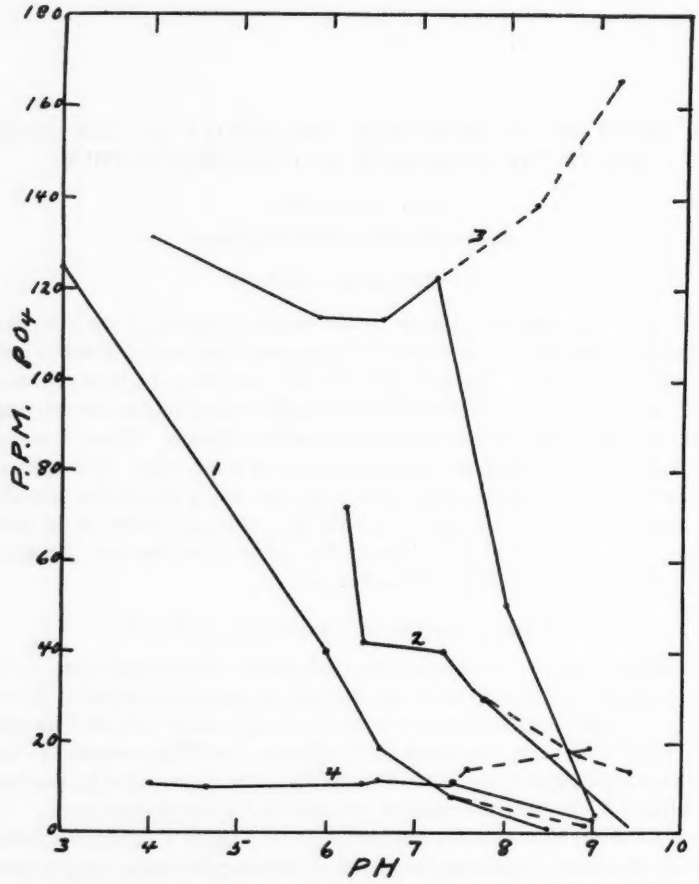

FIG. 1. DESCENDING ORDER OF SOLUBILITY OF CALCIUM PHOSPHATES AND ASCENDING ORDER OF SOLUBILITY OF PHOSPHATES OF IRON AND ALUMINUM WITH INCREASE IN pH

1. Phosphate rock; 2. Di-calcium phosphate; 3. Aluminum phosphate; 4. Iron phosphate. Broken line represents sodium hydroxide alkalinity; and solid line, calcium hydroxide alkalinity.

FACTORS OTHER THAN SOLUBILITY WHICH AFFECT PHOSPHATE AVAILABILITY IN ALKALINE-CALCAREOUS SOILS

Before the study of phosphate availability in southwestern soils had progressed very far it became evident that solubility relations were not the only important factors involved in the apparent phosphate deficiency. The ionization of ortho-phosphate at alkaline reactions (2) and the effect of OH ions on

the absorption of phosphate ions by plants (1) were found to be intimately associated with this phosphate deficiency problem. To review this work briefly, ortho-phosphates undergo step ionization as follows:

$$H_3PO_4 \rightarrow H_2PO_4^- \rightarrow HPO_4^{--} \rightarrow PO_4^{---}$$

Plants were shown to possess a very definite preference for the H_2PO_4 ion, and, since this ion exists largely under acid soil conditions and is present in very small proportion in alkaline soils, it is self-evident that a greater concentration of soluble phosphate in the soil solution of alkaline soils will be required to supply the plants' requirement for H_2PO_4 ion. On growing plants in water cultures it was found that absorption of phosphate ions did not take place at reactions above approximately pH 7.6. This means that crops cannot absorb phosphate ions when the pH of the root-soil contact film is higher than pH 7.6. Thus phosphate nutrition in alkaline calcareous soils is not only a problem in solubility but also one in which soil environmental conditions, which interfere with normal absorptive processes of plant roots and with the proper ionization of ortho-phosphate, must be corrected. In other words, the pH of the soil solution or of the root-soil contact film must be reduced.

ALKALINITY OF THE SOIL SOLUTION IN QUANTITATIVE TERMS

Many of the observations made during soil studies in this laboratory have led to the conclusion that, except where present in unusually excessive concentrations, black alkali is not toxic in most so-called black alkali soils, but rather that such soils are infertile because of the reduced absorption of ions which obtain in the presence of hydroxyl ions (1). This is borne out by the data given graphically in figure 2, in which the concentrations of sodium carbonate, sodium hydroxide, and hydroxyl ion at various pH values between 7 and 10 have been calculated from ionization constants. The concentration of OH ion even at pH 10.0 is much less than we have been generally led to believe and, therefore, the reduction of this to pH 7.6 does not appear to be a difficult task. Although the problem is not so simple as the graph indicates, there are feasible methods of accomplishing this end.

Since all plants are fitted by nature to correct the undesirable environment created by the presence of hydroxyl ions in the soil solution, they enjoy a varied but limited immunity toward black alkali. Reference is made to the exudation of carbon dioxide by living roots. In many soils, roots are aided by the respiration of the soil microflora, but in semi-arid soils there is so little organic matter that crops get very little assistance from this quarter. All of our investigations point to carbon dioxide as the greatest growth-limiting factor in semi-arid soils and, in fact, the very key to their productivity. It is self-evident that free carbon dioxide cannot exist in the presence of hydroxyl ions. If is further self-evident that carbon dioxide is the only means by which the crop can reduce soil alkalinity and thereby promote normal absorption of phosphate.

Figure 2 shows that it should be a relatively simple task for plant roots to reduce the pH of the soil solution when this is not greater than pH 8.5, but that it becomes increasingly difficult above pH 8.5 because of the rapidly ascending nature of the curve above this point. It also is made increasingly difficult because of the fact that all soil solutions are buffered—some very strongly—and, too, in southwestern soils we cannot overlook the resistance to pH reduction which solid-phase calcium carbonate offers. These several fac-

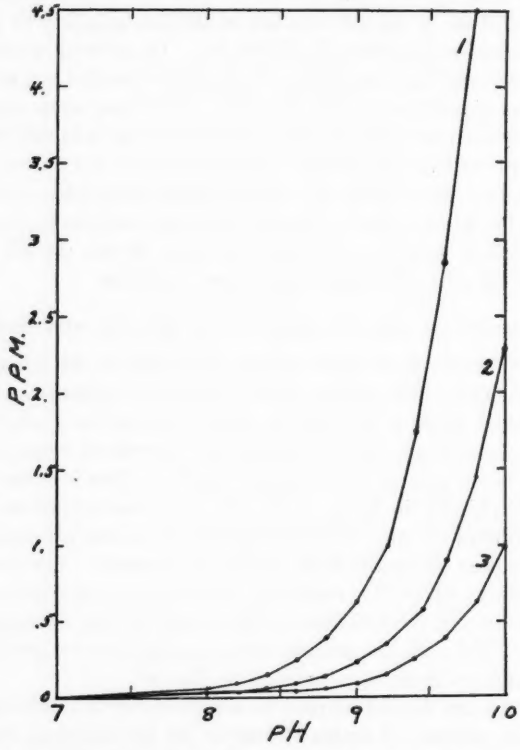

FIG. 2. RELATION BETWEEN pH AND PARTS PER MILLION OF: 1. SODIUM CARBONATE; 2. SODIUM HYDROXIDE; 3. HYDROXYL ION

tors demand such a great expenditure of energy by the crop in reducing or attempting to reduce the pH of the soil solution that the vitality of the crop suffers to such an extent that it becomes necessary to furnish aid artificially. Thus, in the Southwest, we must devise methods of supplying growing crop plants with a constant and adequate supply of carbon dioxide.

In view of the foregoing, it is not surprising to note that practically every procedure employed in the reclamation of alkaline soils is in reality an attempt

to supply the soil with carbon dioxide. Manure and other forms of organic matter supply potential carbon dioxide and stimulate the activities of the soil microflora; gypsum opens up the soil to better aeration; sulfur is oxidized to sulfuric acid, which in turn generates carbon dioxide from the calcium carbonate; and, finally, alkali-resistant crops are used largely because of the carbon dioxide which their roots exude. Thus, methods already in vogue in the cultivation of alkali soil types should be useful in improving phosphate availability. In this connection the remarkable improvement in phosphate availability obtained by Pittman (5) from manuring Utah soils is of interest.

POTENTIAL ALKALINITY OF IRRIGATION WATER

Although the foregoing methods of improving the fertility of alkali soils lead toward greater phosphate availability, there is one phase of the fertility problem which has not received adequate attention and one which should have an important bearing on the phosphate deficiency problem. Reference is made to the *quality* of irrigation water as related to plant-foot absorption. The term *quality* does not refer here to salt concentration, which is the general use of the term, but rather to the potential alkalinity both of the water itself and of the water after contact with the soil in the field. The reaction of alkaline soils is almost entirely a function of the degree of hydrolysis of the sodium-clay exchange complex, which in turn is a function of the composition of the irrigation water and the soil solution. Most irrigation waters are slightly alkaline, and it is not uncommon to find some showing phenolphthalein alkalinity. Furthermore, the reaction of irrigation water is subject to change: for example, bicarbonates change to carbonates on evaporation under the extreme temperatures of the semi-arid climate, alga and other aquatic plants increase the pH of water by extracting their carbon dioxide from the soluble bicarbonates in the water, and finally the hydrolysis of the sodium-clay compound is subject to fluctuation, upon dilution, at each irrigation. All three of these conditions have a definite bearing on phosphate solubility and its subsequent absorption by crops and not only warrant serious consideration in the general problem of phosphate nutrition in alkaline calcareous soils, but offer a medium for solution of the problem; that is, the solution of the problem appears to lie in an economic method of reducing the pH of alkaline irrigation waters. Such a procedure should not only increase phosphate availability but should also tend to increase the rate of water penetration and correct many other factors which are involved in the low fertility of alkaline soils.

EXPERIMENTAL

In support of the preceding discussion, the following experiments, illustrative of the investigations which have been conducted on the problem, are presented.

Experiment 1

The first experiment involves the changes in pH which take place when soils come in contact with water. The three soils selected are representative of the irrigated soils of Arizona. The following is a brief description of the soils, all of which are calcareous and respond to phosphate fertilization:

1. A black alkali soil, sandy loam alluvial type which also contains large amounts of white alkali.
2. A clay-loam soil, which tends to puddle and in which water penetration is poor.
3. A sandy loam soil which has good penetration.

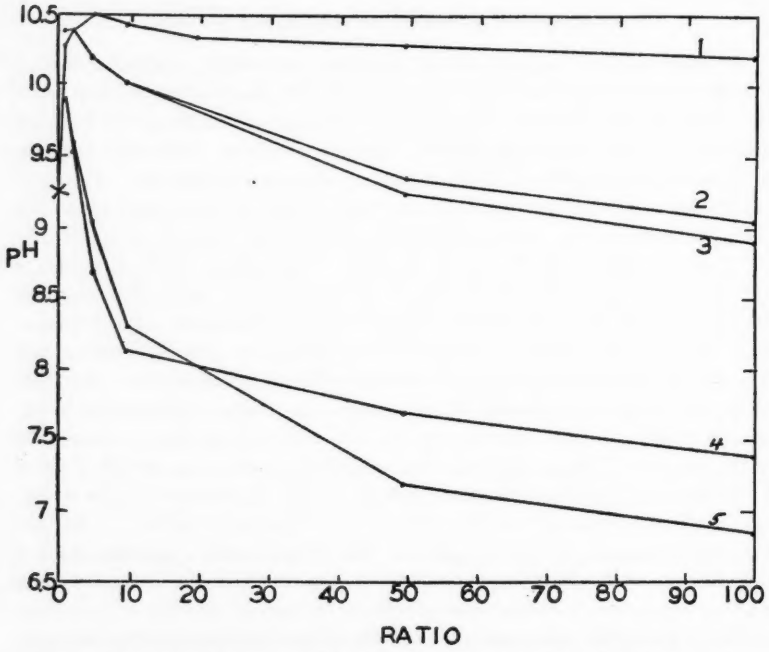

FIG. 3. EFFECT OF VARYING THE SOIL-WATER RATIO ON pH OF SOIL NUMBER 1

1. Boiled distilled water; 2. Boiled tap water; 3. Unboiled tap water; 4. Distilled water plus CO_2; and 5. Tap water plus CO_2.

The soil solution was obtained by packing 1,000 gm. of soil of optimum moisture content in glass percolators, the tips of which dipped below the surface of neutral mineral oil contained in large test tubes, thus preventing contact of the soil solution with air as it dropped from the percolators. Alcohol was used as a displacing liquid. Only 100 cc. of each of the soil solutions was collected, as this was sufficient for the tests. The pH values of these soil solutions were determined with the hydrogen electrode and checked with indicators. The values obtained (pH 9.25 for soil 1, 8.0 for soil 2, and 8.25 for soil 3) are represented in figures 3, 4, and 5 by crosses (X).

To illustrate the effects of dilution on the pH of these soils, that is, the influence of the soil-water ratio upon pH, soil suspensions were prepared in which the ratio of soil to water varied from 1:1 to 1:100. In order to show the manner in which water brings out the potential alkalinity, several different kinds of water were used; namely, distilled water which had been boiled to remove all carbon dioxide, tap water which had been boiled, tap water unboiled, distilled water containing 105 p.p.m. carbon dioxide, and tap water containing 230 p.p.m. carbon dioxide. Boiled distilled water was used to bring out the

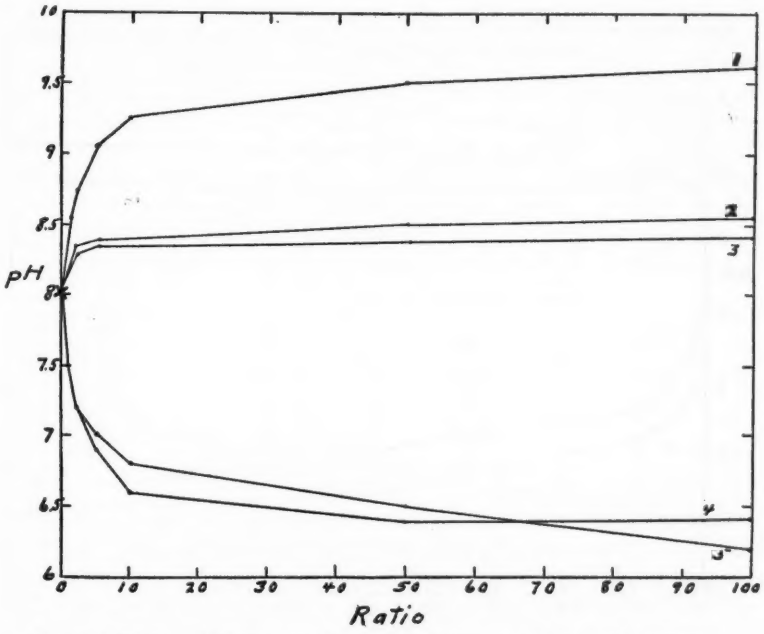

FIG. 4. EFFECT OF VARYING THE SOIL-WATER RATIO ON pH OF SOIL NUMBER 2
1, 2, 3, 4, and 5, same as in figure 3

maximum potential alkalinity; unboiled tap water, to represent irrigation water (well buffered); boiled tap water, to represent the conditions arising when irrigation water is allowed to evaporate in reservoirs or in the field where penetration is slow; and the two waters containing carbon dioxide were used to illustrate the conditions which arise where acidified irrigation water is run on a field of calcareous soil. The pH values were determined with the hydrogen electrode in all cases except in soils 2 and 3 where water containing carbon dioxide was used. In each of these latter soils the pH was determined with indicators. The data obtained are presented graphically in figures 3, 4, and 5.

Soil 1.—This is a black alkali soil, the soil solution of which contains 226,000

p.p.m. salts (total solids) and has a pH of 9.25. At low soil-water ratios there is a rapid increase in pH of the soil for both distilled water and tap water, reaching a maximum of pH 10.5 for the distilled water at a 1 to 5 ratio and tapering off to pH 10.2 at a 1 to 100 ratio because dilution of sodium carbonate and hydroxyl ion is greater than the increase in hydrolysis of sodium clay with dilution. Where a buffered water is used (tap water) the maximum pH is at 1 to 2 soil-water ratio, from which the pH tapers off very rapidly to pH 9.1 for the boiled tap water and to 8.85 for the unboiled tap water. When the waters contain carbon dioxide there is a rapid decrease in pH with increase

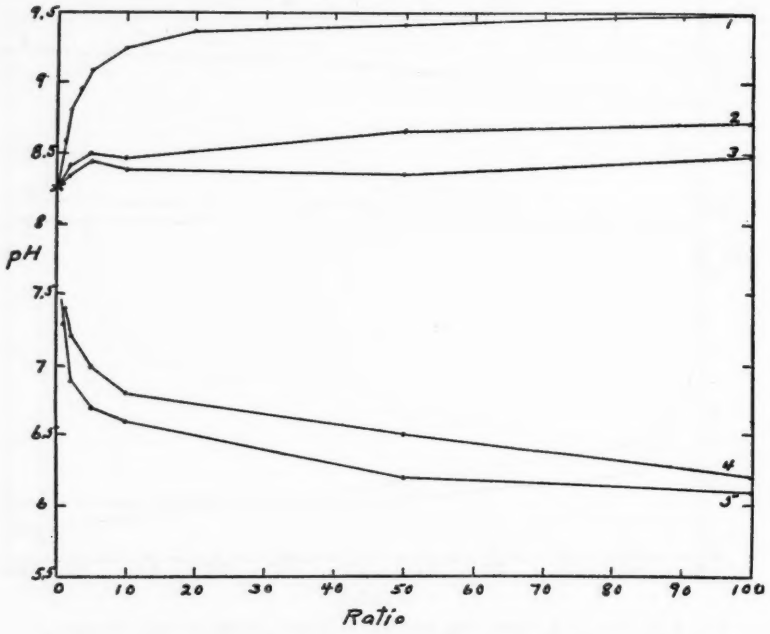

FIG. 5. EFFECT OF VARYING THE SOIL-WATER RATIO ON pH OF SOIL NUMBER 3
1, 2, 3, 4, and 5, same as in figure 3

in soil-water ratio, and here again the buffered water offers the greater resistance to reduction in pH, as it did to increase in pH in absence of carbon dioxide.

Soil 2 and 3.—The general character of the curves for these two soils is the same as for soil 1, except that reduction of pH by the waters containing carbon dioxide is more completely within the feeding range.

It is recognized that increase in pH with increase in soil-water ratio is not so great for tap water as for distilled water, but it must be remembered that reduction in pH of the tap water-soil mixture requires more energy because of

the more highly buffered nature of the system. There seems no question but that there will be an increase in the pH of the soil solution or soil-water system with each irrigation, depending upon the potential alkalinity of the water and the amount of sodium clay in the soil. This pH will, of course, be ultimately reduced to the actual pH of the soil solution as the percentage of water in the soil is reduced. It is thus apparent that the frequent irrigation of semi-arid alkaline soils is not conducive to maximum phosphate availability and absorption by crops, and the whole suggests the importance of a study of the pH of irrigation waters if any great advance in phosphate availability in these soils is to be effected.

Experiment 2

It is plainly evident from experiment 1 that some means of generating carbon dioxide in the soil will help greatly to solve the phosphate problem. The most economical means of accomplishing this in Arizona is by the use of sulfuric acid in small amounts in the irrigation water. A 0.001 *N* solution of

TABLE 1

Phosphate (PO_4) in dry corn plants irrigated with water of pH 3.0, 7.0, and 8.5

REACTION OF WATER	PO_4 IN DRY CORN PLANTS GROWN ON		
	Soil 1	Soil 2	Soil 3
	per cent	*per cent*	*per cent*
pH 3.0	1.50	1.90	2.25
pH 7.0	1.46	1.51	1.55
pH 8.5	1.35	1.48	1.40

sulfuric acid contains 49 p.p.m. H_2SO_4 and gives a hydrogen-ion concentration of pH 3.0. Such a pH should be sufficiently low to generate the small amount of carbon dioxide required to reduce the pH of the soil solution and thus aid the roots in absorbing phosphate. With these facts in mind, the following experiment was conducted.

Three soils, thoroughly representative of our alkaline calcareous types, were selected. Three pots of each were prepared and planted to four corn plants per pot. One pot of each soil was irrigated with tap water adjusted to pH 3.0; another, with tap water adjusted to pH 7.0; and the third, with tap water adjusted to pH 8.5. After 6 weeks the plants were harvested, tops only, and their phosphate contents determined by chemical analysis. The results obtained are given in table 1. Each pot was fertilized with calcium nitrate and ammonium phosphate to insure the presence of ample available phosphate in the soil and thereby eliminate all factors except reaction and carbon dioxide.

This experiment conclusively demonstrates that the absorption of phosphate is governed by the pH of the irrigation water, that the use of alkaline waters reduces the absorption of phosphate by plants growing upon alkaline calcareous

soils, and that reduction of the pH with sulfuric acid, or the carbonic acid generated thereby, increases the absorption of phosphate. Field experiments indicate that similar results are obtainable in the field and are entirely economical with 60° Baumé sulfuric acid available in Arizona at $8 per ton F.O.B. the smelters.

CONCLUSIONS

The phosphate problem on alkaline calcareous soils is not only one of low solubility of phosphate compounds present in the soils themselves, but also one in which the highly alkaline reaction of the soils interferes with the absorption by crops of added soluble phosphates.

The alkalinity of irrigation waters, both of themselves and in association with the potentially alkaline zeolitic compounds in the soil, makes for further reduced phosphate absorption by crops.

Reducing the pH of the irrigation water by addition of small amounts of sulfuric acid greatly increases the absorption of phosphate by plants irrigated with such water.

It is not unreasonable to assume that the addition of acid to irrigation waters will become a standard practice in the not distant future on soils of these types.

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SOME CHEMICAL AND PHYSICAL PROPERTIES OF NORMAL AND SOLONETZ SOILS AND THEIR RELATION TO EROSION[1]

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Soils locally designated as "alkali spots" or "slick spots" are found rather frequently in central Oklahoma bordering the Permian-Pennsylvanian contact. The Sandstone Hill region or Central Cross Timber soils area represents the outcrop of the Pennsylvanian period occurring farthest west in the state. This sandy area without sharp boundary lines separates the Eastern Prairies or Prairie Plains, an outcrop of the Pennsylvanian period, from the Central Prairies or Redbeds of Permian age. It is in or near the borders of these latter two provinces that the alkali spots are most numerous, though their occurrence is not infrequent throughout much of the section.

The presence of these so-called "alkali spots" is probably due to the accumulation of sodium salts in the sediments laid down by the receding sea, as the water in the deeper surface reservoirs evaporated as a result of arid conditions. The lateral extent of an individual alkali spot is usually quite distinct, indicating definite abrupt surface conditions at the time of deposition, accumulation, and formation of the solonchak soil.

As the soluble sodium salts reacted with the base exchange complex Na-clay formed. Rain water later removed the soluble salts to a greater or lesser extent and carried them down into the lower horizons of the profile; but the Na-clay formed, being insoluble in water, was not readily removed in this manner and tended to persist. As the soluble sodium salts were leached out of the surface soil by the rain water, hydrolysis of the Na-clay occurred and NaOH, its soluble product, caused the soil to become more or less alkaline in reaction and highly deflocculated. This retarded further leaching, and with this retardation and existing climatic conditions morphological features characteristic of solonetz soils developed.

The normal profile developed in the absence of salt accumulations has an A horizon varying in depth from just a few inches to 18 inches or more. It is of variable texture but in structure it is generally friable. The B horizon usually

[1] Contribution from the department of agronomy, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma. Published with the permission of the director of the Oklahoma Agricultural Experiment Station.

[2] The writers wish to thank Dr. H. J. Harper for suggestions in the preparation of the manuscript.

is a sandy clay to stiff clay with a blocky, cubical, or angular cloddy structure. With the sandier types prismatic structures are often developed. Claypans have developed in some instances. The parent materials of the area are sandstone and shale.

The solonetz profile where erosion has not been severe usually presents four or five rather distinct horizons. The A_1 horizon is sandy loam in nature and usually ranges from 2 to 6 inches in depth. Its color is usually buff to light brown. Where drainage has been adequate, the A_2 horizon is usually darker brown than the surface layer, as a result of the accumulation of organic matter in this zone. It is not so sandy as A_1 but is usually of a loamy nature. The A_3 horizon is a very thin gray layer occurring over the caps of the columnar B_1 horizon. In some instances its appearance is not pronounced. The caps of the columns in contact with the A_3 horizon have a tendency to be rounded, although this development is not always pronounced. The B_1 horizon is variable in thickness but merges into a cloddy B_2 horizon and then into a more or less cemented structureless mass of high soluble-salt content. Limestone concretions occur frequently throughout the B horizon in many cases. Below this structureless horizon, which is of variable thickness, sandstone is usually encountered.

METHODS USED

The water-soluble constituents were determined by using 1:5 extractions with distilled water. The replaceable bases were determined by using neutral normal ammonium acetate as the replacing reagents. The term "active" is used to designate the amount of calcium or sodium soluble in and displaced by the ammonium acetate solution. The acetate leachate was treated as recommended by Salgado (2) and the sodium was determined by the Barber and Kolthoff (1) method.

The dispersion coefficient was determined by shaking, at the rate of 50 r.p.m., 4 gm. of air-dried soil with 400 cc. of distilled water in straight-walled bottles 12 cm. deep. The bottles were removed from the machine at the end of 24 hours and placed in an upright position for 24 hours, at the end of which time the top 5 cm. were carefully siphoned off and the number of centigrams of material in suspension in 100 cc. was recorded as the dispersion coefficient.

The mechanical analysis of the soils was determined by the Bouyoucos method.

EXPERIMENTAL DATA

The data presented were obtained largely from the exposed surfaces of the normal and the eroded solonetz profiles. Erosion had taken place at least to some extent on the normal soil. Tables 1 and 2 record the results of paired exposures of the normal profile and the nearby solonetz profile. The amounts of the various bases are expressed in terms of milliequivalents per 100 gm. of

TABLE 1

The dispersion coefficient and sodium-calcium ratios of the exposed B horizon of the solonetz profile compared with the A horizon of the normal profile

LOCATION IN STATE (NEAREST CITY)	EXPOSED A HORIZON OF NORMAL SOIL					EXPOSED B HORIZON OF SOLONETZ SOIL				
	Dispersion coefficient	Water-soluble Na	Active Na	Active Ca	Ca/Na ratio	Dispersion coefficient	Water-soluble Na	Active Na	Active Ca	Ca/Na ratio
		m.e.	*m.e.*	*m.e.*			*m.e.*	*m.e.*	*m.e.*	
Guthrie	1.22	0.11	0.86	1.75	2.03	8.14	1.64	6.44	1.65	0.26
Moore	0.72	0.06	0.22	2.85	12.95	18.30	9.60	11.87	3.30	0.28
Moore	0.42	0.13	0.25	1.83	7.32	2.64	1.10	3.03	2.52	0.83
Edmond	1.42	0.06	0.29	2.48	8.55	2.60	0.69	3.08	2.90	0.94
Oklahoma City	1.16	0.07	0.27	2.65	9.81	4.20	2.52	4.59	3.20	0.70
Agra	0.74	0.08	0.21	2.20	10.48	1.96	0.30	1.62	2.20	1.36
Shawnee	0.66	0.10	0.24	2.70	11.25	1.86	1.85	4.10	2.95	0.72
Meeker	0.90	0.04	0.05	1.75	35.00	3.58	4.08	6.55	1.45	0.22
Norman	0.62	....	0.14	2.48	17.72	2.94	1.89	5.94	4.95	0.83
Stillwater	0.80	0.08	0.08	2.75	34.30	4.74	....	9.17	4.30	0.47
Claremore	1.44	0.09	0.54	5.05	9.36	8.78	1.73	7.21	3.10	0.43
Claremore	1.14	0.24	0.56	3.60	6.43	2.72	1.33	3.86	2.65	0.69
Oilton	1.02	0.05	0.17	2.35	13.83	2.06	1.08	3.62	4.60	1.27
Nowata	0.66	0.09	0.46	2.20	4.77	1.98	0.91	4.19	2.20	0.52
Pawhuska	1.08	0.12	0.47	2.10	4.47	3.20	2.27	6.06	3.65	0.60
Claremore	0.94	0.05	0.44	2.45	5.57	1.80	0.82	3.00	2.90	0.97
Claremore	2.18	0.08	0.31	6.90	22.28	2.21	8.89	11.19	9.75	0.87
Valley	0.74	0.14	0.90	3.50	3.89	6.18	2.24	6.22	4.40	0.71
Lela	1.58	0.04	0.51	1.70	3.33	9.50	....	7.66	1.90	0.25
Mannford	0.78	0.09	0.31	2.05	6.61	3.32	1.28	3.99	2.00	0.50
Chelsea	0.86	0.15	0.45	1.60	3.55	1.38	0.51	2.22	1.75	0.79
Hominy	1.30	0.06	0.52	2.85	5.47	2.80	1.38	4.74	1.60	0.34
Stillwater*	0.76	0.06	0.39	2.80	7.17	2.96	2.65	3.94	1.75	0.44
Stillwater	0.40	0.12	0.12	1.20	10.00	1.32	2.11	3.04	0.75	0.25
Stillwater	0.96	0.11	0.14	1.40	10.00	1.36	0.72	2.09	1.25	0.60
Stillwater	0.80	....	0.04	1.65	41.25	1.27	....	2.71	1.20	0.44
Stillwater	0.76	....	0.08	1.45	18.13	1.28	0.72	2.33	0.75	0.32
Stillwater	0.64	....	0.13	1.30	10.00	2.08	....	4.38	1.25	0.29
Stillwater	1.02	0.05	0.27	1.35	4.98	2.78	1.75	3.76	1.45	0.39
Stillwater	0.90	0.03	0.25	1.10	4.45	1.66	....	2.21	0.95	0.43
Stillwater	1.30	....	0.15	0.95	6.33	2.22	....	3.77	2.25	0.60
Glencoe	0.72	0.08	0.19	0.85	4.52	23.52	2.89	10.95	1.95	0.18
Average	0.96	0.08	0.31	2.31	11.12	4.29	2.19	4.99	2.61	0.58

* These soils are not paired samples, but were collected approximately one-fourth mile from each other.

soil. Table 3 shows the pH values of 19 paired soil samples before and after being leached with distilled water.

TABLE 2

The water-soluble and active base content of some typical solonetz profiles

LOCATION AND DEVELOPMENT	DEPTH	WATER-SOLUBLE			ACTIVE					
		Na	Ca	Ca/Na	Na	K	Ca	Mg	Di/ Mono	Ca/Na
	inches	*m.e.*	*m.e.*		*m.e.*	*m.e.*	*m.e.*	*m.e.*		
Stillwater-Farm A:										
Normal profile, horizon A.....	0– 6	0.25	0.59	2.36	0.66	0.16	4.05	1.81	7.10	6.13
Solonetz, exposed horizon B....	0– 1	1.27	0.21	0.17	2.99	0.51	3.10	3.04	1.75	1.03
Solonetz, exposed horizon B....	1–12	1.20	0.27	0.23	5.07	0.51	4.45	3.83	1.48	0.88
Solonetz, exposed horizon B....	12–24	3.71	0.25	0.07	7.78	0.90	5.55	4.33	1.14	0.71
Solonetz, exposed horizon B....	24–36	0.70	0.54	0.77	4.02	1.44	4.05	3.58	1.48	1.01
Solonetz, exposed horizon B....	36–48	0.63	0.14	0.22	4.25	0.23	3.65	2.88	1.46	0.86
Stillwater-Farm B:										
Normal profile, horizon A.....	0– 6	0.38	2.91	7.66	1.05	0.77	6.90	3.21	5.55	6.56
Solonetz, exposed horizon B....	0– 1	7.95	3.02	0.38	12.62	0.72	4.80	3.58	0.68	0.38
Solonetz, exposed horizon B....	1–12	7.88	0.87	0.11	9.29	0.92	4.75	4.89	0.95	0.51
Solonetz, exposed horizon B....	12–24	7.97	7.55	0.95	11.38	0.37	8.75	4.69	1.15	0.77
Solonetz, exposed horizon B....	24–36	3.28	6.60	2.01	8.32	0.80	13.60	3.24	1.85	1.63
Stillwater-Farm C:										
Normal profile, horizon A.....	0– 6	0.35	0.40	1.14	0.84	0.29	5.90	1.98	7.02	7.07
Solonetz, exposed horizon B....	0– 1	3.11	0.40	0.13	6.88	1.02	8.75	3.24	1.52	1.27
Solonetz, exposed horizon B....	1–12	3.26	0.40	0.12	5.78	....	11.25	3.62	.....	1.95
Solonetz, exposed horizon B....	12–24	3.91	0.27	0.07	5.46	0.74	11.60	3.62	2.45	2.12
Solonetz, exposed horizon B....	24–36	2.03	0.40	0.20	7.64	0.79	7.45	3.24	1.27	0.98
Solonetz, exposed horizon B....	36–48	1.35	0.16	0.12	9.00	0.83	6.30	2.80	0.93	0.70
Stillwater-Farm D:										
Normal profile, horizon A.....	0– 6	0.10	0.22	2.20	2.03	0.32	5.00	1.19	2.63	2.47
Solonetz, exposed horizon B....	0– 1	2.17	0.33	0.15	3.59	0.28	3.35	1.90	1.35	0.93
Solonetz, exposed horizon B....	1–12	3.58	0.65	0.18	7.33	0.81	6.90	3.66	1.30	0.94
Solonetz, exposed horizon B....	12–24	3.82	0.54	0.14	7.46	0.46	15.50	4.56	2.53	2.08
Solonetz, exposed horizon B....	24–36	1.85	0.57	0.31	3.97	0.60	8.90	3.13	2.63	2.24
Stillwater-Farm E:										
Normal profile, horizon A.....	0– 6	0.45	0.22	0.49	1.29	0.32	5.70	3.01	5.43	4.43
Solonetz, exposed horizon B....	0– 1	0.83	0.25	0.30	3.39	0.49	4.20	3.21	1.91	1.24
Solonetz, exposed horizon B....	1–12	1.95	0.33	0.17	15.00	0.56	6.35	4.69	0.71	0.42
Solonetz, exposed horizon B....	12–24	3.84	0.27	0.07	6.99	0.79	7.70	5.14	1.65	1.10
Solonetz, exposed horizon B....	24–36	3.34	0.30	0.09	7.50	0.58	20.75	5.14	3.11	2.77
Solonetz, exposed horizon B....	36–48	3.95	1.08	0.27	5.08	0.79	9.70	4.20	2.37	1.91

Although some textural differences existed among the various soils, the general average indicates rather closely the textural conditions of the surface of

TABLE 3

The pH of 19 typical paired soil samples before and after leaching with distilled water

LOCATION	A HORIZON OF NORMAL SOIL PROFILE			B HORIZON OF SOLONETZ PROFILE		
	Soil	Leachate	Leached soil	Soil	Leachate	Leached soil
1	6.48	7.06	7.08	8.67	7.78	8.52
2	6.37	6.65	6.61	8.59	7.80	9.08
3	6.61	6.28	6.56	7.70	7.52	8.03
4	6.80	6.93	7.93	8.07	7.12	8.17
5	5.85	6.96	6.44	8.00	6.93	8.36
6	6.37	6.23	6.56	8.17	6.93	8.48
7	7.12	6.61	7.13	8.54	7.38	8.50
8	6.46	6.72	6.58	6.59	7.28	8.54
9	5.85	6.27	5.88	7.06	7.76	7.68
10	6.14	6.23	6.63	7.54	6.90	8.00
11	6.27	6.20	6.38	8.59	7.72	8.76
12	5.75	6.86	6.66	7.32	7.01	7.76
13	6.05	6.44	6.72	8.46	7.63	8.59
14	6.20	6.30	6.73	7.88	7.01	8.07
15	6.00	6.27	6.20	7.20	7.24	7.58
16	6.06	6.27	6.30	8.10	....	....
17	5.92	6.10	6.34	7.93	7.65	8.31
18	5.60	6.35	6.09	7.08	6.90	7.17
19	7.00	6.10	6.98	7.76	7.13	8.15

TABLE 4

The textural relationships of the soils studied

SOIL	HORIZON	SAND	SILT	CLAY	DISPERSION COEFFICIENT
		per cent	*per cent*	*per cent*	
Solonetz 1	A	45.60	30.00	24.40	0.18
	B	25.60	32.00	42.40	15.50
Solonetz 2	A	63.60	19.00	17.40	0.30
	B	55.60	17.00	27.40	17.54
Solonetz 3	A	36.60	34.00	29.40	0.02
	B	53.60	10.00	36.40	22.28
Normal (samples average 32)	A	43.77	26.68	29.55	
Solonetz (samples average 32)	B	38.38	22.88	38.74	

the normal soils. In table 4 are recorded the dispersion coefficients and mechanical analyses of the A and B horizons of three different solonetz soils indicating the variations in texture of these soils.

TABLE 5

The dispersion coefficient of three badly eroded solonetz soils

LOCATION	HORIZON B_1	HORIZON B_2
1	13.01	26.60
2	6.56	21.70
3	21.74	25.42

TABLE 6

Rate of settling after shaking 4 grams of air-dried soil with 400 cc. of distilled water for 24 hours

SETTLING TIME	EXPOSED B_1 HORIZON OF SOLONETZ SOIL (PERCENTAGE OF SOIL IN SUSPENSION)									
	20	121	1x	10	6	8	12	2	4	29x
min.										
0.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1.0	37.24	24.26	22.40	35.90	37.04	28.22	17.26	30.12	44.92	49.26
2.5	28.90	17.22	18.60	30.74	24.22	21.60	14.42	26.86	39.74	37.90
5.0	25.36	15.70	15.62	25.70	23.16	18.70	11.24	25.90	37.04	33.82
10.0	20.42	12.54	11.42	23.04	18.76	14.54	7.64	21.96	33.72	32.90
15.0	20.34	11.60	10.44	21.60	12.80	13.60	7.06	21.76	32.80	.....
30.0	16.68	9.80	10.64	17.40	12.64	10.76	6.18	20.16	31.60	30.92
hours										
1	12.52	8.20	7.62	16.26	11.68	8.12	3.62	18.56	30.96	27.42
2	9.82	6.84	5.42	11.38	7.22	5.82	2.90	18.46	28.22	29.36
4	7.46	2.71	5.02	9.54	....	5.22	2.86	18.12	26.64	27.40
6	6.04	....	4.82	7.06	....	3.96	1.94	....	25.18	....
8	5.06	....	4.58	6.70	4.46	....	....	....	....	26.20
24	4.70	2.08	2.78	4.20	2.64	2.60	1.96	8.14	18.30	23.52

SETTLING TIME	EXPOSED A HORIZON OF NORMAL SOIL (PERCENTAGE OF SOIL IN SUSPENSION)									
	19	113	2x	9	5	7	11	1	3	28x
min.										
0.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1.0	21.08	11.76	12.64	18.44	25.04	15.32	17.50	10.28	19.86	16.04
2.5	10.14	8.60	8.00	12.66	12.42	10.40	13.48	9.74	13.14	11.90
5.0	6.42	5.08	6.66	7.96	7.24	6.54	8.72	5.56	7.08	5.72
10.0	4.10	4.20	4.80	5.86	5.36	5.16	5.86	5.48	5.70	3.76
15.0	3.18	3.42	3.84	3.88	4.44	5.12	4.44	4.18	3.44	3.42
30.0	2.46	2.64	3.18	3.66	2.96	4.22	3.20	2.76	2.58	2.40
hours										
1	1.44	1.88	2.14	2.44	2.66	3.10	2.58	3.14	2.02	2.36
2	1.66	1.62	2.00	2.14	1.42	2.10	1.90	1.16	1.58	1.52
4	0.98	0.89	1.98	1.22	....	1.68	1.50	1.20	0.74	1.00
6	0.82	....	1.20	....	....	1.90	1.10	1.14	....	....
8	0.98	....	1.04	....	1.32	....	....	....	....	1.14
24	0.80	0.64	1.02	1.12	0.42	1.42	0.74	1.22	0.72	0.72

The dispersion coefficients of the B_1 and B_2 horizons of three badly eroded solonetz profiles were determined as a matter of interest. The results are shown in table 5.

DISCUSSION

The data in the tables indicate the rapidity at which solonetz soils, once the A horizon is removed, may erode. When this stage has been reached these soils have practically no agricultural value, and therefore they should be protected from severe erosion before the B_1 horizon is exposed. Since, however, the A horizon of these soils in this vicinity is only a few inches thick, such soils should be kept in grass as the best means of protection. The grasses growing on these soils where cultivation has not destroyed the native vegetation are principally buffalo (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*). Once this soil has been abandoned after having been in cultivation, and while some of the A horizon still remains, triple awn grass (*Aristida oligantha*) soon occupies the area, perhaps largely because this grass requires such a scant amount of plant food for growth. These soils are very low in nitrogen and available phosphorus.

The high dispersion coefficient of the B horizon of the solonetz soils is not the only reason for their rapid erosion. Such areas are usually devoid of, or support only a sparce, vegetative growth and hence there is no buffer against the agitation of rain drops, as there is on the normal soils where the vegetation may offer considerable protection not only in this manner but also because of extensive root development. This not only applies to the solonetz soils where the B horizon is exposed but to those which have been under cultivation at some previous time and when only a thin A horizon remains. This thin A horizon is usually not capable of supporting a vegetative covering that will offer much protection to the soil and, since rain water cannot penetrate the lower horizons, this thin horizon soon becomes supersaturated with water and erodes away rapidly when it occupies sloping areas. Although the clay content is usually somewhat higher, the high active sodium content and the low calcium-sodium ratio of the exposed B horizon of the solonetz profile readily account for the high dispersion coefficients of these eroded areas compared with the surface soil of the normal profile. An approximate estimation of the replaceable sodium may be calculated from the data by subtracting from the sodium in the acetate leachate that which is given as water soluble. The replaceable sodium is high in the B horizon of the solonetz profile. It appears that where the replaceable sodium is high even though there may be considerable water-soluble sodium, and the active calcium is such that the ratio of active sodium to active calcium is approximately 2.00 or less, the soils are unproductive. Such a condition also indicates a soil with a high dispersion coefficient, and, if it occupies an area of much slope, erosion will be quite severe. It will be noted that the average dispersion coefficient for the B horizon of the solonetz profile is 4.29 compared with 0.96 for the surface soils in the normal

profile. Of course the subsoil of the normal soil has a higher dispersion coefficient than the surface soil, but the data given are presented to show the ability which exposed surfaces, as they now occur, have to withstand erosive influences. The data in table 1 record two solonetz samples having exceptionally high dispersion coefficients. Even when these are excluded, the average is 3.28, hence once these soil particles are agitated into suspension they will be carried away by running water to a much greater extent than the surface soils of the normal profile subjected to a similar environment. This is further substantiated by rate of settling data (table 6), which indicate that there is often more solonetz material in suspension after 60 minutes than of normal surface soil after 2.5 minutes of settling. Material having such a high tendency to remain in suspension would be carried a great distance once it became suspended because the current of the run-off water before and after it enters a stream would likely keep the suspension sufficiently agitated to prevent any but a limited amount of settling.

Although both gully and sheet erosion occur on the soils, the type of gully formed through the solonetz profile is quite different from that occurring where the normal profile is encountered. Where gully erosion occurs, very often the gully has its origin in one of the so-called "alkali spots," where it tends to develop a fan-shaped area though it may work back from the solonetz area into the normal soil if the length of the slope is great enough to deliver considerable amounts of water into that particular water channel, and hence the observer may be led astray as to the initial origin of the ditch. Frequently solonetz areas are encountered where there is no well-defined main gully, but a rather broad eroded area where all the surface soil is gone and many small gullies appear, but as these approach normal soil there is a fusion into one gully with steep sides. The walls of the gullies in the solonetz soils are usually sloping and present a very smooth surface, indicating extreme deflocculation. The gully in the solonetz soils grows through the carrying away of this deflocculated material from the broad sloping sides, and by the force of the water working under the broad sides. Eventually the weight of the protruding soil causes it to cave in. In the normal profile, however, the sides of the gully are steep and the widening of the gully is due to exfoliation while the cutting action is confined very largely to the bottom of the ditch. The typical gully in the normal soil is steep-sided, narrow, and deep, whereas in the solonetz soil it is often indistinct, or broad with sloping sides. As the force of the water works under the sides, and caving takes place, this solonetz gully may also exhibit steep sides, especially where the soil mass is cemented together with limestone concretions.

In the control of erosion on lands where both the normal profile and the solonetz profile are encountered, difficulty may be experienced in the building of terraces if the degraded alkali material is used. Rainwater accumulates and stands on the upper side of level terraces or in the depressions in the terrace causeway on solonetz soils, since the degraded material does not permit any

appreciable amount of moisture to penetrate into the lower horizons of the profile. To cite an example, 3 weeks following a rain a composite sample of water was collected from three different pools standing on the exposed B_1 horizon of some solonetz profiles where terraces were still holding. The water was being lost almost entirely by evaporation, was noticeably red as a result of the presence of colloidal material, and upon examination it showed 0.3 per cent of soil in suspension. If the terrace happens to pass through a solonetz area and the degraded material is used in building the terrace, the terrace is weakened at this point because of the deflocculating effect on the soil particles brought about by the presence of large amounts of sodium and the low calcium-sodium ratio in the soil. The terrace tends to melt away, leaving a broad levelled gap as rain falls on such a fill and as water collects behind it. A further study is being made in the use of degraded alkali material as cores and when mixed with the nearby normal soil in the building of terrace fills.

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THE SEPARATION AND IDENTIFICATION OF THE MINERAL CONSTITUENTS OF COLLOIDAL CLAYS[1]

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There has been much diversity of opinion as to the constitution of clays. Most of the early workers regarded kaolinite as the main constituent. Any variation from the kaolinite formula was ascribed to the presence of free silicic acid and free hydrated oxides of iron and aluminum. At the present time there appear to be two viewpoints regarding the constitution of colloidal clays. Mattson (13), in his investigations on the laws of soil colloidal behavior, regards the soil colloids as complexes of indefinite structure and varying composition. He believes them to be amphoteric salts of weak acids (silicic, humic, etc.) and weak bases (chiefly iron and aluminum), formed as a result of the mutual precipitation of electropositive (basic) sols and electronegative (acidic) sols at or near isoelectric conditions (10, 11, 12). This view of the constitution of colloidal clays, although based on more modern conceptions, conforms, in general, to the view held by Van Bemmelen (3). On the other hand, a number of investigators believe that colloidal clays consist for the most part of definite crystalline compounds with stoichiometrical compositions. Especially since the introduction of improved methods and techniques, such as the X-ray, has this view become more widely accepted.

The X-ray studies of Hendricks and Fry (7) indicate that montmorillonite-beidellite, Ordovician bentonite (or a mixture of montmorillonite and quartz), and halloysite are common mineral constituents of soil colloids. Bauxite was found to be present in two of the samples examined. They did not find any evidence of feldspar or mica.

Kelley, Dore, and Brown (8), as a result of their X-ray investigations, concluded that the crystalline materials of bentonites and soil colloids examined by them belong to the montmorillonite-beidellite group of clay minerals, and are essentially crystalline magnesium aluminum silicates in which the magnesium at the surface of the particles has been replaced, giving rise to the exchange

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properties. The magnesium in the interior of the particles is non-exchangeable, but becomes exchangeable when exposed by grinding.

As a general statement, previous work indicates that the main constituents of colloidal clays are free silica, free aluminum and iron oxides, base exchange compounds, and other hydrated aluminum and iron silicates. The present paper deals with an investigation of methods for the separation and identification of the mineral constituents of colloidal clays.

PREPARATION OF COLLOIDAL CLAYS

The colloidal clays used in this study were prepared from California white and Wyoming yellow bentonites, nontronite, Colby silt loam subsoil, and Vesper sandy loam subsoil. These materials were free of carbonates and contained little or no organic matter. The treatment given them, which follows, is similar to that described by Chucka (6). They were ground to pass a 40-mesh sieve, digested on a steam plate for about 2 hours with *N* NaCl solution, and then leached in a Büchner funnel with about 500 cc. of *N* NaCl solution per 25 gm. of material. The excess NaCl was washed out with approximately 85 per cent by volume ethyl alcohol. The materials were then dispersed in a dispersion apparatus arranged as suggested by Bouyoucos (4), after which they were suspended in water in the ratio of 25 gm. per 10 liters of water. After the materials had settled for 24 hours, the supernatant suspensions were siphoned off and passed through a supercentrifuge at such a rate as to produce a colloidal suspension in which the particles were 0.0001 mm. or less in diameter. These suspensions were used in the subsequent experiments.

SEPARATION OF MINERAL CONSTITUENTS BY PHYSICOCHEMICAL METHODS

Separation by specific gravity

A technique suitable for specific gravity separations of fine particles has been perfected by Volk (20) in which tetrabromoethane is used as the heavy liquid. He separated quartz and muscovite from the soil fraction of particle size 0.002 to 0.0003 mm. in diameter. It was thought, therefore, that this method might be used on the fine clay fraction of particle size 0.0001 mm. and less in diameter, but, under actual trials, separations were not possible because the colloidal material coagulated in the tetrabromoethane. When bromoform was substituted as the heavy liquid, this coagulation was apparently prevented, but lack of time did not allow completion of tests including centrifuging. The procedure perfected for getting the dispersion is as follows: Coagulate the suspension with NaCl, transfer to centrifuge tubes, and wash free of salt with approximately 85 per cent by volume ethyl alcohol by centrifuging and decanting. Wash with anhydrous acetone and finally with anhydrous ether. Dry the material at room temperature in a moisture-free atmosphere and then at 70°C. for several minutes to drive off the last traces of ether. Finally, evacuate and disperse as recommended by Volk, but use bromoform, and then proceed with the centrifuging.

Crystallization in a bomb

Mineralogists have prepared crystalline alumino-silicates by subjecting mixtures of the oxides to high steam pressure. The same procedure has also been used for producing larger crystals from corresponding micro-crystalline compounds. This suggested the possibility of inducing a crystal growth of the micro-crystalline compounds present in colloidal clays, and thus facilitating their separation and identification.

Experiments were conducted in which two white bentonites, a yellow bentonite, and colloids extracted from Vesper sandy loam and Colby silt loam subsoils were subjected to a steam pressure of about 200 atmospheres at a temperature of about 400°C. For this purpose a bomb[3] constructed of special tool steel so as to withstand pressures up to 100,000 pounds per square inch was used. The bomb is a hollow, thick-walled cylinder, $5\frac{1}{2}$ inches long and $2\frac{3}{4}$ inches in diameter. The top half is threaded to fit a heavy bolt. The colloidal clay in gel form was placed in a small platinum crucible, covered, and inserted into the bomb. The bolt was screwed in as tightly as possible, the threads having been covered with graphite to prevent any leaks. The bomb was then placed in a furnace for several days at a temperature of 400°C., which is above the critical temperature of water.

In all cases, upon examination under the microscope after treatment, only quartz crystals, formed probably from the free silica present, were observed. Otherwise, the samples appeared the same as before the bomb treatment, and were found to have the same base-exchange capacities. It is possible that treatment for longer periods (several months), and at higher pressures, might effect crystallization or crystal growth of other constituents.

Electrodialysis

Electrodialysis has been used by many investigators to study exchangeable bases and other plant nutrients. According to Mattson (14), it also offers a means of studying the changes taking place in the colloid complex after desaturation has occurred. In the following experiments, an attempt was made to effect a separation of some of the mineral constituents, especially iron oxide, by prolonged electrodialysis.

A suspension of colloid from yellow bentonite which contained several per cent of iron, and a soil colloid extracted from Colby silt loam subsoil and known to contain free iron oxides were electrodialyzed in a Mattson cell for 72 hours at a potential of 75 volts. The solutions in the outer compartments were renewed every 4 hours for the first 12 hours, and then once every 12 hours thereafter. At the end of 72 hours, the materials were removed and analyzed. They were found to have the same exchange capacities and chemical compositions as previous to electrodialysis, indicating that electrodialysis, carried out

[3] The bomb used was devised by Professor R. C. Emmons.

in this manner, is not a suitable means of separating the main mineral constituents of colloidal clays.

Differential flocculation

Robinson and Holmes (15) attempted to separate colloidal material into fractions of different compositions by fractional coagulation. They evaporated heavy dispersions of soil colloids and found that on concentration a large part of the material coagulated, while the other part remained in suspension. Upon analysis, however, they found no difference in the two fractions, and concluded that separation of minerals of soil colloids could not be effected by this means.

With the same idea in mind, the following experiments were conducted: A suspension of sodium-saturated Colby colloid, which contained about 2 gm. per liter of dry matter, was used. A solution of NaCl sufficiently dilute so as to flocculate only a portion of the suspended material was added. Analyses of the flocculated and unflocculated portions gave identical results, indicating that no separation had been effected. In another experiment the colloid was saturated with barium, washed practically free of excess salt, and dispersed. The suspension was then centrifuged until some of the clay was thrown down. It was thought that perhaps the exchange material saturated with the heavy barium atom would come down first, leaving the non-exchange mineral constituents in suspension. Upon analysis, however, both fractions were found to have the same composition. Another sample of the Colby colloid was saturated with sodium and centrifuged until some of the material came down. Here again, upon analysis, no difference was found between the material thrown down and that remaining in suspension.

The results obtained thus far indicate that differential flocculation is not a suitable means for separating the constituents of colloidal clays.

SEPARATION OF MINERAL CONSTITUENTS OF COLLOIDAL CLAYS BY DIFFERENTIAL SOLUBILITY

Extraction of free silica with sodium carbonate

In order to test the solubility of silica in sodium carbonate, a sample of pure quartz was powdered and separated into fractions of various sizes. These fractions were treated in platinum dishes with different concentrations of sodium carbonate until completely dissolved. The results are summarized in table 1.

These data show that a 2 per cent solution of sodium carbonate is satisfactory for dissolving colloidal silica. This extraction probably also dissolves most, or all, of the free alumina, but has little action on the other constituents. Base-exchange capacity determinations were made on samples of colloids from white bentonite and Colby silt loam before and after treatment with sodium carbonate, and the results are given in table 2.

These results show that boiling with sodium carbonate solution up to as high a concentration as 10 per cent for 12 hours has no appreciable effect on

the base-exchange material. Since the other mineral constituents with the exception of silica and free alumina are probably as resistant as the exchange material, it may be assumed that they were not affected appreciably by the sodium carbonate treatment. The sodium carbonate treatment when properly regulated as regards strength and length of treatment appears, therefore, to be a satisfactory method for separating free silica and possibly alumina.

Some difficulty was encountered in obtaining pure sodium carbonate. Of several brands tried, Merck's Reagent grade anhydrous sodium carbonate proved satisfactory for use without further purification. Ordinary C.P. sodium carbonate may be purified by digesting a concentrated solution in a nickel

TABLE 1

Solubility of finely powdered quartz in various concentrations of Na_2CO_3 solutions

APPROXIMATE SIZE OF QUARTZ PARTICLES	TIME REQUIRED FOR COMPLETE SOLUTION AT BOILING TEMPERATURE		
	2 per cent Na_2CO_3	5 per cent Na_2CO_3	10 per cent Na_2CO_3
mm.	*hrs.*	*hrs.*	*hrs.*
0.003 to 0.0006	36	36	36
0.0006 to 0.0003	24	22	14
0.0003 to 0.00015	12	12	8
< 0.00015	10	8	6

TABLE 2

Effect of Na_2CO_3 treatment on the base exchange capacities of a bentonite and a soil colloid

SAMPLE	BASE-EXCHANGE CAPACITIES PER 100 GM. OF CLAYS UNTREATED AND TREATED WITH SODIUM CARBONATE			
	Untreated	Boiled 12 hours with sodium carbonate		
		2 per cent	5 per cent	10 per cent
	m.e.	*m.e.*	*m.e.*	*m.e.*
Bentonite	147	145	149	147
Colby colloid	98	96	96	98

container for 24 hours and filtering off the coagulated impurities. After this treatment is repeated, the salt is recrystallized. It should now be pure and ready for use.

Extraction of free iron oxide with sodium acid oxalate

The strength of HCl required to dissolve the free iron oxides of soil colloids at a reasonable rate is so great as very seriously to attack the other constituents. Oxalic acid is commonly recognized as a good solvent for iron oxides. Robinson and Holmes (15) found that, in addition to iron oxide, considerable amounts of combined alumina and silica were dissolved from colloids by rather strong oxalic acid at an elevated temperature.

Tamm (18) used acid ammonium oxalate in an attempt to separate the soil colloids from the rest of the soil, the idea being that the iron oxides, silica, and alumina existing in the colloidal state would dissolve.

In the following experiments, a solution of sodium acid oxalate, 0.1 *N* with respect to both sodium oxalate and oxalic acid, was used. One-half gram samples of Colby colloid and Vesper colloid were shaken intermittently with 300 cc. of the oxalate solution at room temperature for 3 days. The suspensions were coagulated, and the material was washed several times with ammonium acetate and then treated with 2 per cent sodium carbonate solution to dissolve any free silica. Base-exchange capacities of the samples were then determined, after which total analyses were made. The results, together with those of analyses of untreated samples, are summarized in table 3.

TABLE 3

Analyses of Colby and Vesper colloids, untreated and treated with sodium acid oxalate and sodium carbonate

	AMOUNTS OF CONSTITUENTS AND BASE-EXCHANGE CAPACITIES			
	Colby colloid		Vesper colloid	
	Untreated	Treated	Untreated	Treated
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	56.1	60.0	54.8	55.7
Al_2O_3	24.1	27.0	26.6	27.3
Fe_2O_3	14.9	8.5	7.3	6.3
K_2O	0.7	0.7	4.5	4.7
MgO	2.9	3.1	3.1	3.2
Total	98.7	99.3	96.3	97.2
	m.e.	*m.e.*	*m.e.*	*m.e.*
Base-exchange capacity per 100 gm.	98	154	53	60

In the case of the Colby colloid treated with oxalate solution, there was a significant decrease in the percentage of Fe_2O_3 and a corresponding increase in SiO_2 and Al_2O_3, while the potassium and magnesium content increased only slightly. The untreated colloid was reddish brown in color, while the treated sample was yellowish gray, similar to the color of the iron silicate, nontronite. This indicated that practically all of the free iron oxides were removed by the oxalate treatment, and the iron remaining was in the form of iron silicate. The removal of the iron oxides resulted in a large increase in base-exchange capacity, even when calculated on the basis of the weight before removal of the iron. This suggested that the iron oxide was either physically or chemically bound up with the base exchange material, thereby reducing the base exchange capacity. Lundblad (9), after treating soil colloids with ammonium oxalate, also found increases in base capacities.

The Vesper colloid, on the other hand, had much the same composition and base-exchange capacity after treatment as before. The color of the untreated colloid was a yellowish gray both before and after treatment. It was concluded that the Vesper colloid contains a relatively small amount of free iron oxides, most of the iron being present probably as a silicate.

A colloid separated from a Hawaiian laterite known to contain large amounts of iron oxides was treated with the oxalate solution. The color before treatment was a dark brown, whereas after treatment it was almost white. The iron oxide content was reduced from 44.2 per cent to 3.4 per cent. This was a striking example of the solvent action of the oxalate solution on iron oxides.

Samples of colloids prepared from the iron silicate, nontronite, and a yellow bentonite, were unchanged in color, composition, and base-exchange capacity after treatment with the oxalate solution, indicating that no free iron oxides were present.

In all of the foregoing experiments there was some solution (5 to 20 per cent) of material other than the iron oxides, but from the analyses there was no indication of solution of any definite compound other than the iron oxides. It is concluded that, if properly regulated, treatment of colloidal clays with sodium acid oxalate, although not ideal, may be used to advantage in certain cases for separating the free iron oxides present.

Solubility in hydrofluoric acid

Preliminary tests indicated that some silicate minerals are attacked by HF much more readily than others. Finely powdered talc dissolved almost instantly in 2.5 per cent HF (approximately 1 cc. concentrated 48 per cent reagent diluted to 20 cc.), whereas muscovite and tremolite did not dissolve appreciably in 10 minutes. This suggested that the mineral constituents of colloidal clays might have a differential solubility in dilute HF.

A sample of hydrogen-saturated white bentonite gel containing 0.2 gm. of dry material was treated in a platinum dish for 1 minute with 50 cc. of 0.5 per cent HF by weight, and the suspension filtered with suction by means of a paraffined Gooch crucible fitted with a pad of filter paper pulp and held in a paraffined suction flask. This filtration took about 2 minutes. The residue was washed 10 times with 0.05 *N* HNO_3 and analyzed. It was found that, although an appreciable amount of the material had dissolved, the composition of the residue was the same as that of the original material.

It seemed possible that the bentonite used contained only one mineral, and hence, samples of Vesper colloid and Colby colloid, known to contain different constituents, were subjected to the same treatment. In both cases, appreciable quantities of material were dissolved, but the analyses of the residues and untreated samples gave identical results. It was concluded that the mineral constituents of colloidal clays do not have a marked differential solubility in HF, probably because the clay is so finely divided that, in a strong solvent like HF, differences in rate of solubility are difficult to measure.

Extraction with ammonium acetate after fine grinding

It was thought that if the minerals present in colloidal clays were ground fine enough in a ball mill, some of them might become soluble in a weak solvent like ammonium acetate solution. Since the crystals of the base-exchange compounds presumably are sufficiently porous to allow reactions with solutions to go on internally as well as at the surface, their solubility should not be increased markedly by grinding. Smolik (17), and Kelley, Dore, and Brown (8) have reported marked effects of grinding soil colloids and bentonites on the exchangeability of otherwise non-replaceable bases.

A sample of purified white bentonite, ammonium-saturated, containing 7.3 per cent of non-replaceable MgO, was ground for 90 hours in a steel ball mill provided with chrome alloy steel balls. At the end of the run, the sample was found to be highly contaminated with iron from the mill. A weighed portion of the ground sample was leached with neutral *N* ammonium acetate and the leachate analyzed. It was found that a large portion of the non-replaceable magnesium present in the original sample, together with some silica and a little alumina, had become soluble in the ammonium acetate.

In order to eliminate contamination as much as possible, efforts were made to obtain a more resistant mill. A porcelain-lined bowl was found to be unsatisfactory, 3 gm. of material being ground off the bowl during a 2-day run. A bowl made of high quality carbon tool steel proved to be quite satisfactory. It was specially hardened and tempered so as to be highly resistant to abrasion. The cover of the bowl was provided with a three-fourths inch hole for the purpose of replacing the atmosphere in the bowl with dry air so as to lessen the tendency of the material to stick to the sides of the bowl and to the balls, thus making the grinding more effective. The hole was closed with a threaded steel stopper.

A sample of purified ammonium-saturated white bentonite was dried at 150°C. for 24 hours and then ground in the ball mill for 72 hours. It was then leached with ammonium acetate and the leachate analyzed. About 15 per cent of the non-exchangeable magnesium present and 1 per cent of the silica were extracted, but tests for soluble aluminum and iron were negative. This indicated that a magnesium silicate was being made more soluble by the grinding. The sample was then treated with sodium acid oxalate to remove any free ferric oxide arising by contamination from the mill, and finally with Na_2CO_3 to remove any free silica. A base-exchange capacity determination agreed with the base-exchange capacity of the original material.

Kelley, Dore, and Brown (8) believed that the non-replaceable bases are made replaceable by means of grinding. This would imply that the base capacity would be increased by an amount equal to the amount of base made replaceable. The preceding experiment, however, did not bear this out, but rather suggested that other minerals than the base-exchange compounds were being affected by the grinding treatment. Further grinding experiments with other clays are now being carried on.

IDENTIFICATION OF MINERAL CONSTITUENTS OF COLLOIDAL CLAYS

Identification of an iron silicate as a mineral constituent

From the preceding experiments and from the work of other investigators, it appears that not all of the iron present in colloidal clays is in the oxide form. The existence of an iron silicate mineral in clays has been suggested by Robinson and Holmes (15), and the iron silicate, nontronite, has been identified in soils (1, 5) with a petrographic microscope. Unfortunately, petrographic methods have not been adapted to the study of particles finer than 0.005 mm. in diameter.

There is no agreement as to the exact composition of nontronite, some ascribing to it the formula, $Fe_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, and considering it to be the iron isomorph of kaolinite, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$; others give $Fe_2O_3 \cdot 3SiO_2 \cdot XH_2O$ as the formula. One of the difficulties involved is obtaining pure samples.

TABLE 4

Analyses of purified colloids from nontronite and bentonite

SAMPLE	SiO_2	Fe_2O_3	Al_2O_3	MgO	$\frac{SiO_2}{Fe_2O_3 + Al_2O_3}$	BASE-EXCHANGE CAPACITY PER 100 GM.
	per cent	*per cent*	*per cent*	*per cent*		*m.e.*
Nontronite no. 1	57.0	38.9	0.8	2.3	3.9	127
Nontronite no. 2	55.3	41.3	0.4	1.1	3.6	144
White bentonite no. 2	67.2	1.4	28.1	3.7	3.9	139

Colloidal suspensions prepared from two different samples of nontronite obtained from the Woody district, California, were treated with sodium carbonate to remove any free silica and alumina. Base-exchange capacities were determined on the two samples, and total analyses made. The results are summarized in table 4, together with an analysis of a purified white bentonite.

These data confirm the idea of the existence of an iron exchange compound similar in nature to the aluminum exchange compound. However, the analyses indicate that the ratio of SiO_2 to Fe_2O_3 of the compound is 4 to 1 rather than 3 to 1 or 2 to 1. The presence of MgO shows that the material is probably not altogether pure, which might account for the variation from the ratio of 4 to 1. Table 4 shows that the base-exchange capacities of the purified nontronites agree fairly well with the base-exchange capacity of the bentonite.

An X-ray pattern obtained of one of the purified nontronite samples is very similar to that of a purified white bentonite.

The color of the Vesper and Colby colloids after treatment with sodium acid oxalate to remove free iron oxides approached that of nontronite, giving further credence to the idea that an iron silicate-exchange compound similar to

the aluminum-exchange compound is present in some colloidal clays containing iron other than that in the oxide form.

Fixation of cations by wetting and drying

Besides free silica, free oxides of aluminum and iron, and the iron and aluminum base exchange compounds, there are probably other intimately mixed minerals in most colloidal clays. This is indicated by the grinding experiments. It was thought that further evidence of this might be obtained by a study of the effect of wetting and drying of colloidal clays in the presence of salts, since Volk (21) found that by alternate wetting and drying of soils in the presence of KCl potassium is fixed by the clay fraction of soils in a form not extractable with ammonium acetate; and since an artificial mixture of

TABLE 5

Analyses of purified colloids from yellow bentonite and Colby silt loam subsoil, both untreated and wetted and dried 40 times in the presence of KCl

	AMOUNTS OF CONSTITUENTS AND BASE-EXCHANGE CAPACITIES			
	Yellow bentonite		Colby colloid	
	Untreated	Wetted and dried 40 times with KCl	Untreated	Wetted and dried 40 times with KCl
	per cent	*per cent*	*per cent*	*per cent*
SiO_2	64.9	63.8	56.1	55.4
Al_2O_3	27.6	26.8	24.1	23.7
Fe_2O_3	4.0	3.9	14.9	14.6
MgO	2.8	2.9	2.9	2.7
K_2O	Trace	1.5	0.7	2.0
Total	99.3	98.9	98.7	98.4
	m.e.	*m.e.*	*m.e.*	*m.e.*
Base-exchange capacity per 100 gm.	116	118	98	96

silica gel, aluminum hydroxide, and calcium hydroxide did not possess this fixing ability, he concluded that the potassium reacts with a silicate mineral to form a difficultly soluble potassium compound, which he believed to be muscovite.

It was decided to test the fixing power of purified colloidal clays in relation to their base-exchange capacities in order to determine whether it was the base-exchange material or some other mineral that reacted with the potassium. Samples of a purified yellow bentonite and a Colby colloid were saturated with potassium and alternately wetted and dried 40 times at 70°C. in the presence of excess KCl. The samples were then extracted with ammonium acetate to remove any soluble and exchangeable potassium present. Base-exchange capacities were determined and total analyses made. The results, together with those of analyses of untreated samples, are given in table 5.

These data show that a considerable amount of potash was fixed by the clays with no significant change in the base-exchange capacities. If the potash had reacted with the exchange compounds to form an insoluble potassium aluminum or iron silicate, one would expect a reduction of the base-exchange capacity. Therefore, it was concluded that there are other minerals present besides the exchange compounds which react with the potassium. As further evidence of this, it was found that when the clays were saturated with potassium and wetted and dried in the absence of any excess KCl, no potassium was fixed, nor was there any decrease in the base-exchange capacity. This showed that the potassium in the exchange form does not react further with the base-exchange material.

Samples of yellow bentonite saturated with Na, Ca, and Mg were also wetted and dried in the presence of excess NaCl, $CaCl_2$, and $MgCl_2$ respectively. It was found, however, that none of these cations were fixed, and no effect on the base-exchange capacity was noted. Apparently, potassium is the only cation studied which can be fixed by the clay minerals.

Possible use of ultra-violet microphotographs

If the individual particles of a colloidal suspension could be photographed, some indication of their differences in shape and other properties might be obtained, and hence their identity established by comparison with known minerals. Work in other fields has indicated the possibility of photographing particles of approximately 100 $\mu\mu$ in diameter by the use of the ultra-violet microscope. This suggests its use for studying colloidal clays. Preliminary tests on the absorption spectra of some colloidal clays indicate that clays absorb ultra-violet light of the wave length used with the microscope, and, therefore, there is some hope that the ultra-violet microscope might be suitable for the study of clays. Unfortunately, the apparatus was not available for use at the time of this investigation.

Loss of water at elevated temperatures

If it could be shown that the percentage losses of water from colloidal clays at elevated temperatures are related to the losses from certain minerals at these same temperatures, this would indicate the presence of these minerals. Accordingly, samples of two different bentonites, variously saturated, and a sample of finely powdered sericite $(H,K)AlSiO_4$, were heated successively at higher temperatures in a muffle furnace. Since ferrous iron was absent, the actual loss of water should be represented by the loss in weight. The loss in water at the different temperatures was calculated in percentages of the weight of the sample after being heated at 100°C. for 24 hours. The results are given in table 6.

In the case of the bentonites, there is a distinct maximum loss of water between 550° and 650°C. This temperature interval corresponds to that at which the base-exchange material loses its base-exchange properties, as shown by Kelley, Dore, and Brown (8), and since the bentonites are largely composed

of base-exchange material, this water loss can be ascribed to that substance. Baver and Horner (2) also obtained a maximum loss in water at about this same temperature range. There is some indication of a second rise in loss of water at 850°C. in the case of the white bentonite and an initial rise at 350° and 450°C. in the case of the yellow bentonite, which may be due to the presence of minerals other than the exchange material. Since the sericite shows no distinct maximum, but rather a uniform loss over the temperature range studied, its presence in the bentonites is not demonstrated. Obviously, before any definite conclusions regarding this method of identifying the clay constituents are drawn, other finely powdered minerals in pure form should be tested.

TABLE 6

Loss of water by bentonites and sericite on heating for 24-hour periods successively at temperatures indicated

TEMPERATURES OF SUCCESSIVE 24-HOUR PERIODS THAT SAMPLE WAS HEATED	WATER LOST DURING EACH HEATING PERIOD, BASED ON WEIGHT AFTER HEATING AT 100°C. FOR 24 HOURS						
	White bentonite			Yellow bentonite			Sericite
	H-saturated	Na-saturated	Ca-saturated	H-saturated	Na-saturated	Ca-saturated	
°C.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
250	0.46	0.00	0.30	0.73	0.00	0.31	0.46
350	0.88	0.23	0.95	0.74	0.32	1.11	0.40
450	1.09	0.46	0.66	1.10	1.11	0.67	0.73
550	1.09	1.66	1.31	0.92	1.75	1.18	0.53
650	2.29	2.49	3.14	2.93	3.50	3.87	0.72
750	0.59	0.83	0.66	0.92	0.41	0.78	0.40
850	0.75	1.57	1.09	0.55	0.49	0.56	0.13
950	0.33	0.37	0.00	0.00	0.00	0.00	0.07

Chemical analyses and stoichiometrical calculations of results to fit probable minerals

Total analyses were made on two different bentonites and two soil colloids after the removal of free silica, alumina, and iron oxide. The data are given in table 7.

If the exact composition of the exchange material, the magnesium compound, and the potash compound were known, it would be possible to allocate stoichiometrically the results of the chemical analysis to definite minerals, and thus present a complete picture of the minerals in soil colloids.

From previous work, it appears that the base-exchange material probably has a SiO_2 to R_2O_3 ratio of 4 to 1. Since Volk (20) found muscovite in the fraction of soil 0.002 to 0.0003 mm. in diameter, it may be assumed for trial purposes that the potash present in colloidal clays can be ascribed to muscovite, $K_2O \cdot 3Al_2O_3 \cdot 6SiO_2$. The grinding experiments indicated the presence of a magnesium silicate in the white bentonite, and for trial purposes the mag-

nesium present in colloidal clays may be ascribed to talc, a hydrated secondary magnesium silicate. The analysis of an ignited sample of talc corresponded to the formula $4MgO \cdot 3SiO_2$. The iron is probably present as an iron silicate exchange compound.

Using the results of the chemical analyses reported in table 7, calculations were made in which the potash present and stoichiometrical amounts of alumina and silica were allocated to muscovite, and its percentage was calculated. Similarly, the iron and necessary silica were allocated to an iron silicate exchange compound having a SiO_2 to Fe_2O_3 ratio of 4 to 1; the magnesium and the necessary silica, to talc. The silica and alumina remaining presumably made up an aluminum exchange compound; its percentage and silica to alumina

TABLE 7

Chemical composition of bentonites and soil colloids after removal of free silica, alumina, and iron oxides, and mineral composition based on stoichiometrical allocations of chemical constituents to minerals assumed to be present

	CHEMICAL AND MINERAL COMPOSITION OF BENTONITES AND SOIL COLLOIDS									RATIO $\frac{SiO_2}{Al_2O_3}$ OF ALUMINUM EXCHANGE COMPOUND	BASE-EXCHANGE CAPACITY PER 100 GM.
	Percentages of oxides by total analysis					Percentages of minerals by stoichiometrical calculation					
	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	Talc	Muscovite	Iron exchange compound	Aluminum exchange compound by difference		
											m.e.
White bentonite no. 1....	67.5	22.4	1.65	0.0	7.3	21.2	0.0	4.2	74.6	3.9	160
Yellow bentonite.....	65.9	26.6	4.0	0.0	2.6	7.8	0.0	10.4	81.8	3.6	120
Colby colloid.....	60.0	27.0	8.5	0.7	3.1	9.0	5.9	21.2	63.9	2.7	154
Vesper colloid.....	56.7	26.0	6.3	4.7	2.8	8.3	37.9	16.2	37.6	3.6	60

ratio are reported. The results of all of these assumptions and stoichiometrical calculations are given in table 7.

If it is assumed that the ratio of silica to alumina in the aluminum exchange compound is 4 to 1, then, in the case of the white bentonite the assumptions and results of the calculations fit the chemical analyses very closely; in the case of the yellow bentonite and Vesper colloid reasonably well, but not so satisfactorily in the case of the Colby colloid.

It should be noted that the exchange capacities of the four samples correspond reasonably well with the sum of the iron and aluminum exchange materials present, with the exception of the yellow bentonite, in which case the exchange capacity is low. Variations of the ratio of silica to alumina from

the assumed value, and irregularities in the exchange capacities may be accounted for by imperfect allocations of the constituents to minerals. It is possible that some of the iron and magnesium should be allocated to mica, and that small amounts of minerals other than those mentioned may be present. Obviously, additional information is needed before a satisfactory picture of the mineral composition of colloidal clays can be drawn.

Attempts at preparation of the aluminum base exchange compound

Since the aluminum exchange compound is often the most important constituent of colloidal clays, it would be extremely helpful if its exact composition were known. A number of artificial alumino-silicates possessing base-exchange properties have been prepared, but none of these have been found to be similar in certain respects to the base-exchange material found in colloidal clays.

The base-exchange compound of bentonites has been shown by several investigators to be similar to that found in soils. It has been suggested (16, 19) that these bentonites were formed from feldspathic volcanic ash which was deposited in water or submerged after deposition. Presumably, hydrolysis took place rapidly, and the water became alkaline, about pH 8.4. The feldspathic ash under these conditions decomposed, giving rise to the bentonites containing large amounts of base-exchange material.

Attempts were made to prepare the base-exchange material by subjecting finely powdered albite to alkaline weathering treatments. The material was leached and digested with various concentrations of Na_2CO_3 and $NaHCO_3$ at different temperatures for various lengths of time up to several weeks. In some cases, compounds were formed which possessed high base-exchange capacities, but they were found to decompose easily in dilute acids, indicating that they were similar to the common artificial zeolites and were not the true soil base-exchange compounds. In no instance was there any indication of the formation of a base-exchange compound similar to that found in soils.

Since colloidal clays show properties similar in some respects to finely powdered mica, they might possibly arise from this mineral under certain weathering conditions. Laboratory experiments to test this possibility are suggested as a promising field for further research.

SUMMARY

The purpose of this study was to investigate some of the possibilities of separating and identifying the mineral constituents of colloidal clays. The results may be summarized as follows:

Colloidal clays were subjected to steam pressure of about 200 atmospheres in a bomb for several days. The colloidal silica crystallized out as quartz, whereas the other constituents were unaffected.

Prolonged electrodialysis and attempts to flocculate colloidal clay suspensions differentially proved unsuccessful as means for separating the clay constituents.

A 2 per cent solution of sodium carbonate at boiling temperature for several hours dissolves free silica from colloidal clays without affecting the base-exchange material. Prolonged treat-

ment in the cold of colloidal clays (known to contain free iron oxides) with a solution of sodium acid oxalate (0.1 *N* with respect to sodium and hydrogen) removed the free iron oxides, but also dissolved other constituents to some extent. No differential solubility of the constituents of colloidal clays in dilute HF was noted.

Grinding clays in a ball mill followed by extraction with ammonium acetate and other solvents offers much promise as a means of separating some of the clay constituents. Preliminary experiments indicate that a magnesium silicate may be extracted from bentonite, while the exchange material is unaffected.

Further evidence of the existence of an iron silicate exchange compound is presented. It is shown to be similar in composition and nature to the aluminum exchange compound.

Colloidal clays fixed considerable amounts of potassium in a form not exchangeable and having no effect on the base-exchange capacity, indicating the presence of minerals other than the base-exchange compounds.

Total analyses were made of some colloidal clays after the removal of free silica, alumina, and iron oxide, and stoichiometrical allocations of the constituents were made to fit the minerals thought likely to be present. In three cases out of four the data fitted the assumptions reasonably well, indicating the possible presence of talc, muscovite, and the exchange compounds having a SiO_2 to R_2O_3 ratio of 4 to 1.

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BOOK REVIEWS

A Textbook of Organic Chemistry, Third Edition Revised. By JOSEPH SCUDDER CHAMBERLAIN. P. Blakiston's Son & Co., Inc., Philadelphia, 1934. Pp. xxv + 873, tables 17. Price $4.00.

In his Preface to the Third Edition, the author notes that "So far as the present revision affects the rest of the text there have been a few changes introduced in order to agree with modern electronic theories and with the latest researches in the field of carbohydrate chemistry. The chemical and physical conditions under which reactions take place have also been added, where previously omitted."

The new edition has in part been condensed, and changes have been made in the arrangement of the subject matter. The book is made up of three parts; namely, Part I—A-Cyclic Compounds, Aliphatic Series; Part II—Cyclic Series; and Part III—Supplementary Topics. Pages 801 and 802 contain a list of books of reference, and pages 803 to 842, inclusive, comprise two appendixes.

In making the revision, the author was guided by his teaching experience and by comments and suggestions received from various sources. Altogether, he has been fortunate in developing a text which will be even more useful than it has been in the past. Teachers of organic chemistry, as well as students, will find this text both helpful and useful.

Perkin and Kipping's Organic Chemistry, Part III, Entirely New Edition. By F. STANLEY KIPPING and F. BARRY KIPPING. W. & R. Chambers, Ltd., Edinburgh, 1934. Pp. viii + 342.

This is a new edition of *Perkin and Kipping's Organic Chemistry*. The authors state that "The present volume has been written as a continuation of Part I and II of Perkin and Kipping's Organic Chemistry, and is intended mainly for the use of students who are working for an Honours Degree Examination. It is hoped that it may also be helpful to teachers, and to others who are interested in the more recent developments of certain branches of organic chemistry."

There are 21 chapters in Part III. The numbering of these is a continuation of that for Parts I and II. The topics dealt with in the several chapters of Part III are: The Electronic Formulae of Organic Compounds; The Physical Properties of Organic Compounds; Geometrical Isomerism; Geometrical Isomerism of the Oximes and other Compounds of Tervalent Nitrogen; Optical Isomerism; Optically Active Compounds of Nitrogen, Tin, Silicon, Sulphur, etc.; Cycloparaffins and Cyclo-olefines; Olefinic Compounds; Ketones, Ketonic Acids, and Ketenes; Isomeric Change; The Configurations, Synthesis, and

Glucosidic Structures of the Monosaccharides; Disaccharides and Polysaccharides; The Monocyclic Terpenes and Related Compounds; Dicyclic Terpenes and Related Compounds; Sesquiterpenes, Open-chain Terpene Derivatives, and Rubber; Cartenoids, Pyrones, Anthocyanins, and Depsides; The Structure of Benzene, and Aromatic Substitution; The Orientation of Benzene Derivatives; Polycyclic Hydrocarbons; Alkali Metal Compounds and Some Derivatives of Arsenic; Compounds in which Elements Show Abnormal Valencies; Steric Hindrance; and Heterocyclic Compounds. The Index covers the three parts.

The authors have made a distinct contribution to the resources of the teacher of organic chemistry. As they note in the Preface: "Whether our selection of the subjects included in this book is the best or otherwise is no doubt a matter of opinion, but it is based on the results of many years of experience in teaching this branch and grade of chemistry."

A Laboratory Manual for the Chemical Analysis of Water and Sewage. First Edition. By E. F. ELDRIDGE and F. R. THEROUX. Edwards Bros., Inc., Ann Arbor, Michigan, 1935. Pp. iii + 201.

The forward march of sanitation has made us realize the significance of water supplies and sewage disposal in the organization and functioning of modern society. Every municipality, to say nothing of the larger political divisions of the United States, is obliged to give more and more thought to methods and procedures for assuring its population of a satisfactory supply of potable water. Good water for domestic and industrial uses and effective methods for the disposal of domestic and trade wastes are matters of general concern. Hence, the need for reliable laboratory manuals dealing with the chemical analysis of water and sewage! The present volume, aside from the Preface, is made up of three sections and an appendix. Section I deals with methods of analysis; Section II, with reagents and standard solutions; and Section III, with chemistry and discussion of methods.

The authors note that "The book contains specific directions in outline form for making the chemical determinations necessary for the control of water and sewage treatment plants, the analysis of polluted water, and the examination of industrial wastes. Each determination is accompanied by calculation formulae, many of which are numerically illustrated." The authors also point out that the manual will be useful to water and sewage treatment plant operators, plant chemists, sanitary engineers, and instructors in our colleges and universities.

Practical Methods in Biochemistry. By FREDERICK C. KOCH. William Wood & Company, Baltimore, 1934. Pp. 7 + 282, figs. 17, tables 35. Price $2.25.

In the rapidly expanding field of biochemistry, there are many questions which constantly call for the devising of new methods of study and for the

improvement of laboratory technic. The author has rendered a service to chemists in having brought together the information given in *Practical Methods in Biochemistry.*

"The beginner in biochemistry," says the author, "should have good fundamental training in chemistry, physics, and general biology. Chemistry is so important that the preliminary work should include a good course in the theoretical and practical aspects of quantitative analysis, a working knowledge of the application of the fundamental laws of physical chemistry to solutions and gases, and the mastery of the more important fundamental facts and concepts of organic chemistry. Biochemistry is the application of these laws, concepts, facts, and methods to the study of any field in biology. Every biological activity involves some chemical change in one or more constituents in the system under consideration."

The three parts of the book are entitled, respectively, The Chemistry of Cell Constituents; the Chemistry of the Digestive Tract; and Blood and Urine. In Part I, we have chapters on carbohydrates, lipins, proteins, nucleoproteins and nucleic acids, and hydrogen ion concentration. The chapters in Part II are designated; respectively: Salivary Digestion; Gastric Digestion; Intestinal Digestion; and Bile. The chapters in Part III are entitled: Blood and Hemoglobin; The Quantitative Analysis of Blood; The Quantitative Analysis of Urine; and The Chemical Examination of Urine for Pathological Conditions. Pages 221 to 274 are devoted to the appendix, which has to do with general laboratory instructions and contains much specific and useful information for the laboratory worker.

Bergey's Manual of Determinative Bacteriology. By DAVID H. BERGEY. Williams & Wilkins Company, Baltimore, 1934. Pp. xvi + 664.

This is the fourth edition of a book widely known and widely used. The successive revisions have undoubtedly added value to the book. The author has been assisted by a committee of the Society of American Bacteriologists. This committee consisted of Robert S. Breed, Frank M. Huntoon, Bernard W. Hammer, E. G. D. Murray, and Francis C. Harrison. "The Committee on Manual," states in the Preface to the Fourth Edition that "The interest in the Manual by bacteriologists has increased greatly, during the past two years, not only on the part of those in the United States but also those in other parts of the world, as indicated by the number of reprints of descriptions of new organisms sent to the Committee by the authors, and also by numerous helpful suggestions for the improvement of the Manual." New genera have been recognized and descriptions of about 50 new species have been included in the book.

The Introduction is followed by suggestions for the use of the Manual in classifying unknown organisms; abridged key of the bacterial families, tribes, and genera; how bacteria are named and identified; bacteriological code; classification of the organisms as arranged in six orders, and the corresponding

numbers of families, tribes, and genera. The authors are to be commended for the effective arrangement of the subject matter and for the earnest and successful effort to provide the greatest accuracy in the descriptions of the several organisms. As they note in the Introduction: "No organism can be classified before we have determined, through detailed study, its morphologic, cultural and pathogenic characters."

One can readily understand why the earlier editions of the book have been so popular, not only in the United States but also in foreign countries. It constitutes a reference work which should be on the shelf of every worker directly or indirectly concerned with bacteriological technic.

Plant Life, A Textbook of Botany. By D. B. SWINGLE. D. Van Nostrand Company, Inc., New York, 1935. Pp. xiv + 441, figs. 290. Price $3.00.

The author has made a distinct contribution to the teaching and reference resources of our botanists. As he points out: "The student will find the subject of botany presented in this book in a somewhat different way from that commonly used. The prevailing tendency is for a morphological approach, the consideration of function being incidental. The result is that students find their textbooks heavy and dull, and they get little comfort from the fact that trained botanists see them teeming with interest. . . . . In this text an advance is attempted in the method of presentation. Use is made of the fact that our interest in plants and animals centers around life processes—methods of obtaining and utilizing food, methods of avoiding the dangers that beset them on every hand, and the ways by which they are perpetuated through endless generations. Activities in which the plant participates constitute the central theme, and structures are described as mechanisms by which these activities can be carried out."

The Preface and the Introduction are followed by eight parts, entitled, respectively: The Living Plant; Plants and Their Surroundings; Plants and Their Food; The Growth of Plants; Reproduction in Plants; The Different Kinds of Plants; Plants Past and Present; and Relation of Plants to each other and to Animals. In writing the book, the author has been painstaking as to detail and has succeeded in preparing an attractive as well as a useful volume. The publishers are to be commended for the quality of their part of the work.

The Theory and Practice of Silviculture. By F. S. BAKER. McGraw-Hill Book Company, Inc., New York, 1934. Pp. xiv + 502, figs. 87, tables 51. Price $5.00.

Silviculture has always been a subject of major economic interest. Its importance has been emphasized in recent years by the more intelligent planning of the use of land resources in different countries. In the United States particularly the withdrawal of large areas of land from agricultural production has called attention to the need for more careful planning in the use of our lands now in forests or to be reserved for the growing of forest trees. Trees like

cultivated crops, have their insect enemies and fungous diseases. They have as distinct a relation to the soil as do cultivated crops. The growing of trees is, therefore, deservedly a popular subject.

We are told by the author that "Readers who are familiar with other works on silviculture, both American and European, will find the arrangement of the early chapters unusual and perhaps confusing, for it has long been customary to discuss chapter by chapter the climatic and edaphic factors and their effects upon the processes of growth reproduction and so on. The arrangement has been revised here. Physiological processes are discussed primarily and note is made of how each is affected by varying different site factors."

Chapter I, which follows the Preface, constitutes an introductory statement. This, in turn, is followed by Parts I to V, entitled, respectively: Plant Physiology; Forest Ecology; Systematized Silvicultural Experience; The Forest Itself as a Source of Silvicultural Knowledge; and Silvicultural Literature. The designations of the chapters in Part I are: Forest Genetics; The Water Cycle; The Carbon Cycle—Photosynthesis; The Nitrogen and Mineral Cycles; Growth of Trees; Reproduction of the Forest; and Injury, Disease and Death of Forest Trees. In Part II, we find chapters on Forest Types and Sites; Form and Composition of Stands; Density of Stands; Tolerance; The Theory of Succession; and Crown Classification. The third part is made up of chapters on Silvicultural Systems Depending on Seed for Reproduction; Coppice Forests; The Analysis of Silvicultural Systems, and Intermediate Cuttings. There is only one chapter in Part IV, entitled: Field Studies in Silviculture. Part V contains two chapters, entitled Applied Silviculture and Applied Silviculture—Western United States, respectively.

The book represents a distinct and valuable contribution on the subject of silviculture. Both the author and publishers are to be commended for having done their work well.

A Study of the Sediments of the North Baltic and Adjoining Seas. By STINA GRIPENBERG. Helsinki-Helsingfors, 1934. Pp. 231, tables 28, figs. 45.

The data reported in this volume are of distinct interest to the specialist as well as to the more general reader. The scope of the work is indicated in the Preface as follows: "In 1924 Professor Rolf Witting, Director of the Thalassological Institute of Helsingfors, suggested that I should undertake the examination of a number of bottom samples which were to be collected from the Gulf of Finland, the Gulf of Bothnia and the North Baltic during the yearly cruises of the s/s Nautilus. This suggestion was followed, and the results of the investigation are set forth in the present paper. About a hundred and thirty samples, collected during the years 1924–1930, were examined. The chief value of an investigation of this kind, apart from a mere knowledge of the character of the sediments, is its bearing on the early history of the Baltic Sea. In this respect, the results presented are only to be regarded as a contribution to the subject, since an examination allowing of more definite and detailed conclusions

would have demanded not only chemical and mechanical, but also mineralogical and biological analyses of the samples."

The nature of the contents of the treatise is indicated by the designation of the chapters, namely: Introduction; Chemical Analysis; Mechanical Analysis; Preliminary Treatment; The Samples; and Discussion. The Bibliography contains 136 titles. Among others, the students of soil and soil erosion will find much of interest in this report.

A Program for Land Use in Northern Minnesota. By OSCAR B. JESNESS, REYNOLDS I. NOWELL, and associates. The University of Minnesota Press, Minneapolis, 1935. Pp. xvi + 338, figs. 46, tables 89. Price $2.50.

The subject of land use is now receiving much attention, both from the economic and sociological point of view. Most of our Public Domain has passed into private ownership. We now find ourselves compelled to reexamine our entire land-use problem and to outline programs and procedures best calculated to conserve the national interests. We are told by the authors that "The object of the study on which this volume is based has been to assemble such facts and to develop their relationship to land use problems. Those who have participated in the work are not under the illusion that it speaks the final word on the subject. They look upon it rather as an introductory approach toward a better understanding of the problem and hope that it will be viewed as such." The authors also note that "This is the second volume dealing with the problems of land use to be published by the University of Minnesota Press. The first, Land Utilization in Minnesota: A State Program for the Cut-over Lands, published in 1934, was the report of a committee appointed by the governor and is now out of print."

The book contains 12 chapters and an index. The several chapters are designated as follows: The Background; Description of the Region; Present Uses of Land: Natural Areas; The Economic and Social Consequences of Planless Land Use; Present Policies and Programs of Adjustment; Land Classification and Zoning; Improved Utilization of Private Forest Lands; Acquisition and Utilization of Land for Public Purposes; Improved Use of Agricultural Land; Problems Involved in Moving Farm Families; Adjustments in Local Government; and Translating Proposals into Effective Programs.

The book is well documented and illustrated, and represents a valuable contribution on the subject of land use.

A Commercial and Economic Geography. By NEIL F. MORRISON. The Ryerson Press, Toronto, 1934. Pp. xv + 557, figs. 135.

The major divisions of the book are devoted to: General Principles; Economic Products; The Dominion of Canada; and The British Empire. The first of these consists of seven chapters, designated, respectively: The Influence of Topography upon Commerce and Industries; The Influence of Climate upon Commerce and Industries; The Distribution of the World's Population; The

Inter-Relationship of Commerce and Civilization; The Development of Trade Centres; The Development of Transportation and Storage; and Agencies which Hinder Commerce. The second division comprises chapters on: Cereals; Fruits and Vegetables; Sugar, Beverages, Spices and Tobacco; Live Stock, Meats and Dairy Products; Fish; Leather; Textiles; Forest Resources and Industries; Rubber; Power; Coal; Petroleum; Iron; Clay and Clay Products; The Precious Metals; and Other Minerals. In the third division, we find chapters on: Ontario; Quebec; New Brunswick; Nova Scotia; Prince Edward Island; Manitoba; Saskatchewan; Alberta; British Columbia; The Yukon Territory; The Northwest Territories; Canadian Agriculture; The Grain Business; Canada's Forests and Forest Industries; Canada's minerals and Mineral Industries; Canada's Commercial Fisheries; Canadian Furs; Canada's Manufacturing Industries; Canada's Transportation Facilities; and Canada's Trade Relations. In the fourth part, the five chapters are designated, respectively: British Possessions in Europe; British Possessions in Asia; British Possessions in Africa; British Possession in Oceania; and British Possessions in the Americas.

Much useful information has been brought together in this volume. The reader will be able to obtain, as it were, a bird's eye view of a great political and economic domain. He will also recognize that the author has made a successful effort to show that Canada is but a part of a greater empire.

Rural Britain To-Day and To-Morrow. By JAMES A. S. WATSON. Oliver & Boyd, Edinburgh and London, 1934. Pp. xxiii + 161, Illus. 12.

Those who know their rural England will find much pleasure in reading this little book. It is reminiscent of the old and offers inspiration for the new. In the introductory statement by Walter E. Elliot, Minister of Agriculture and Fisheries, we are told that "This is a survey of the country, the countryside and its crops, the countryside and its stock, the countryside and its villages and roads, its schools, its buses and its wireless sets, and all that arises out of them. The countryside as it is cultivated and inhabited is the truest picture of a people."

The book contains 12 chapters, entitled, respectively: The Changing Countryside; Wresting a Living from the North Lands; Fishermen and Farmers in North-East Scotland; Lowland Scotland; From the North to the Midlands; East Yorkshire and the Fens; Women's Institute; Tradition and Experiment in the West; The South-Eastern Counties; East Anglian Industries; The West Country; In Corbett's Day and Now; and Conclusion.

In the concluding paragraph of the book, we find this: "Country life is changing, as farming is changing, in some ways regrettably, but on the whole for the better. The disadvantages of isolation, of long dark winter nights, of gruelling hard work on the land, are gradually being mitigated. We only need to give the countryman a fair reward for his toil in order to make his life happier than it has ever been. And apart from financial anxieties the life on the land is still the best of all lives for men and women to lead."

America's Capacity to Produce. By EDWIN G. NOURSE and associates. The Brookings Institution, Washington, 1934. Pp. xiii + 608, numerous tables and graphs. Price $3.50.

In preparing this volume, the author had the benefit of the collaboration of Frederick C. Tryon, Horace B. Drury, Maurice Leven, Harold G. Moulton, and Cleona Lewis.

The present volume is Publication No. 55 of the Institute of Economics of the Brookings Institute. The following may be quoted from the Foreword: "In the light of existing conditions and current experimentation in the realm of economic organization, the present moment seems opportune to examine anew the foundations of economic progress. Is there adequate reason to suppose that the economic activities of our people could be organized on a sustained level which would permit ample food, adequate clothing, comfortable housing, and a reasonable minimum of education and recreation for all members of society? If so, what is the type of economic organization and, more particularly, what are the ways of conducting the affairs of an economic society so organized which would assure the attaining of such a permanent high standard of material well-being."

The Director's Preface, Foreword, and Introduction fully describe the purpose which lay behind the preparation of the book. Part I deals with raw materials; Part II, with fabrication; and Part III, with services. There are six appendixes and an adequate index. Part I includes six chapters, on: Agriculture; Coal and Coke; Petroleum; Copper and other Non-Ferrous Metals; Cement and other Earth Materials; and Conclusions on Capacity of the Mineral Industries. In Part II, we find chapters on: Manufacturing: General Considerations; Food Products; Textiles and Clothing; Automobiles and Tires; Paper Making, Printing and Publishing; Iron and Steel; Other Manufactures; and Conclusions on Manufacturing Capacity. In Part III, the several chapters comprise: Electric Power Utilities; Transportation; Merchandising; Money and Credit; The National Labor Force; and Conclusions. Appendix A has to do with Methods Used in Adjusting Figures for Agricultural Capital; Appendix B, with Measuring Productive Capacity in Mining; Appendix C, with Note on the Statistics of Rated Capacity of Portland Cement Mills; Appendix D, with Notes on Electric Utility Capacity; Appendix E, with Detailed Labor Data and Computation Methods; and Appendix F, with Statistical Tables.

Like other publications of the Brookings Institution, the present volume is substantial and authoritative. The subject matter is presented in a most interesting way.

Economic Development in Modern Europe. By CLIVE DAY. The Macmillan Company, New York, 1933. Pp. xiv + 447. Price $2.50.

The purpose which prompted the author to write this book is indicated in his statement: "In this sketch of economic development I have attempted

something approaching the form of constitutional history. The reader must look elsewhere for the incidents of the economic narrative, and for a more extended treatment of such particular topics as commerce, credit, and labor. This book aims to present for study the institutions of the two most important branches of production,—agriculture and manufacture, and to suggest their relations to the political and social conditions of the times."

There are in the book 19 chapters, a list of references, and an index. The treatment of the subject matter is indicated by the designations of the chapters, as follows: England in the Eighteenth Century; The Industrial Revolution in England; England in the Nineteenth Century; English Trade and Manufacture, 1873–1914; English Manufacture Since the War; England: Post-War Problems; France to 1789; France: Agriculture; France: Manufacture; Post-War France; Germany; German Manufacture, 1871–1914; Post-War Germany; Russia Before and After Emancipation; Organization of Russian Agriculture; The Russian Peasant; Russian Manufacture: Early Forms; Russian Factory Industry; and The Russian Revolution.

The reader of the book is readily impressed with the significance of the land factor in the economic development of modern Europe as described by the author. In all of the European countries mentioned by him, and in some much more than in others, the volume and character of agricultural commodities produced and their movement into the channels of trade have played a prominent rôle in influencing social as well as economic conditions—national and international. The return from the land has been affected, on its part, by the fertility of the soils in different European countries. The student of land and soil problems, as well as the economist, the sociologist, the historian, and the general reader will find much information of absorbing interest in this book.

Outline of Town and City Planning. By THOMAS ADAMS, With a Foreword by Franklin D. Roosevelt. Russell Sage Foundation, New York, 1935. Pp. 368, illus. 126. Price $3.00.

In the Foreword of the book, President Roosevelt says: "City planning is as old as civilization, but among the most important needs of our modern civilization is the proper regulation of both urban and rural development. It is especially true in America, where urban expansion has been exceptionally rapid and has tended in recent generations toward over-concentration, and where rural industries continue to bulk so large in our national life. Often this has led to blighted areas and serious economic waste. To meet these needs we must exercise more foresight in regulating the development of land.

There is an Author's Preface; an Introduction dealing with: Object of City Planning; Scientific Basis of City Planning; the Art of City Planning; Problems in City Planning; Public Policy and Leadership; and the City Planner and Practice. Part I of the book is designated, "Early Efforts in Town and City Planning"; and Part II, "Modern Phases of Urban Growth and City Planning."

There are four chapters in the first part, entitled, respectively: Ancient City

Planning; City Planning in Europe in the Middle Ages; City Planning During and After the Renaissance Period; and Significance of Early Efforts in City Planning. In Part II, we find the following named chapters: Formative Influences of Modern Civic Growth; Developments in the United States before 1900; New Forces in Urban Growth in the United States; City Planning in the United States between 1900 and 1909; Recent Developments in City Planning in the United States; Town Planning Outside the United States; Aims and Methods of Modern City Planning in America; and the Future of City Planning. The Appendix represents a summary of aspects of city planning problems, and deals with the topics of Engineering; Landscape Architecture; Architecture; Sociology; Economics and Finance; and Law. There are two pages of bibliographical notes and an Index.

This book is a welcome addition to our literature on the subject of town and city planning. It is well balanced, and the story in it is well told.

Food Products, Beverages, Rubber, Tobacco, and Miscellaneous Manufactures Based on Vegetable Products 1917–27. Canadian Department of Trade and Commerce. And *Food Products, Beverages, Rubber, Tobacco and Miscellaneous Manufactures Based on Vegetable Products* 1932. By F. A. ACLAND. Ottawa, 1929 and 1934.

These are statistical reports on the subjects mentioned in the titles. The data have evidently been got together with the usual care and accuracy and will be studied with appreciation by statisticians, economists, agronomists, and others.

Report for 1933 Rothamsted Experimental Station. Harpenden, England.

The report falls into two sections: one dealing with the field work on fertilizer and cultivation problems at Rothamsted, Woburn, and many outside centers in various parts of England; the other summarizing the laboratory investigations, the details of which are to be found in the 52 scientific papers and 29 technical papers published in 1933. Full abstracts of all scientific papers dealing with the laboratory findings are given in the report. Agricultural advisers, teachers, students, and others interested in the technical advancement of farming will find the results of the year's experiments at the Rothamsted Experimental Station as set forth in this report of considerable importance.

JACOB G. LIPMAN.

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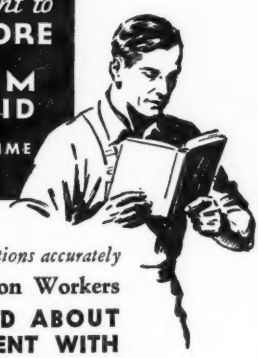

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